Widebody Cabin Water Spray Optimization Tests

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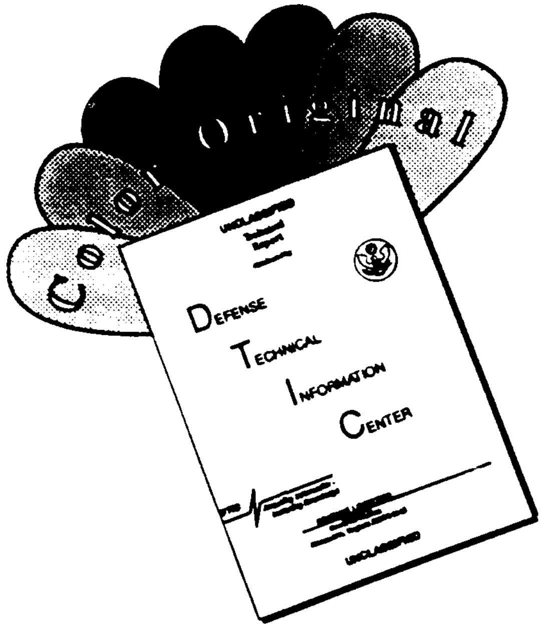

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16. Abstract

Nine full-scale tests were conducted in a modified DC-10 test article as part of an aircraft cabin water spray optimization study. The purpose of the study was to test several spray configurations by varying the orientation of the nozzles, the flow rate, and the quantity of water sprayed, while keeping the fire conditions constant, in an attempt to minimize the amount of water required to effectively suppress a postcrash aircraft fire and improve occupant survivability. The tests were used to validate optimization tests previously conducted in the narrowbody 707 test article.

The initial test series employed a full-zone spray system, extending across the width of the fuselage, consisting of 7 zones, each containing 12 nozzles. A thermocouple was centrally mounted at ceiling height in each of the 8 foot long zones, allowing for the activation of a particular zone when the temperature reached a pre-determined value. A second series of tests were run in which the original zones were divided in half, producing 5 zones on either side of the fuselage centerline for a total of 10. Each of the 10 zones contained 6 nozzles. The survival time was extended between 41 and 103 seconds, depending on zone configuration, discharge activation temperature, and cabin location.

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EXECUTIVE SUMMARY

A safety improvement beyond the fire hardening of cabin interior materials can be achieved by using a low flow rate onboard cabin water spray system (CWSS). Originally developed by SAVE (Safety Aircraft and Vehicles Equipment) Ltd., the system consists of an array of nozzles located throughout the cabin, filling the entire volume with a fine mist. Although the system can offer an additional 2 minutes of escape time in typical postcrash fire scenarios, the initial design added a significant amount of weight. In an effort to curtail the weight penalty, a study was undertaken to test and develop a zoned system which could provide a level of protection equivalent to, or better than, the level of protection offered by the SAVE CWSS by using less water and, hence, less weight.

Nine tests were conducted in a modified DC-10 fuselage to investigate the performance of an optimized, zoned CWSS by varying the orientation of the nozzles, the temperature of secondary zone activation, the flow rate, and the quantity of water used. Previous tests had shown that the best method of maximizing the effectiveness of the water was to divide the CWSS into zones, with activation of discharge within each zone based on zone temperature, thereby discharging water only in the immediate vicinity of the fire origin and area of fire spread. By eliminating the amount of wasted spray in remote areas of the cabin, more efficient use of the water spray is facilitated. A secondary benefit of a zoned CWSS is that it allows the layer of smoke and gases to "restratify" in the more remote areas of the cabin, reducing the exposure to combustive products of passengers attempting to deplane in the event of an emergency. This was confirmed during optimization tests conducted in the narrow-body 707 fuselage.

During the first set of tests in the wide-body DC-10, the optimized spray system consisted of seven zones which could be individually activated when the temperature reached a predetermined value of 300 °F, as measured by a ceiling mounted thermocouple in the center of each zone. Because of the large fuselage diameters associated with wide-bodied aircraft, it was believed that even more effective use of the water spray could be achieved by dividing the zones in half, thereby allowing for the activation of water spray in only one side (half) of the fuselage. Both spray configurations showed that a small quantity of water was very effective in safeguarding against the effects of an external fuel fire. As much as 89 seconds of additional escape time could be obtained by using only 21 gallons of water.

INTRODUCTION

PURPOSE.

The purpose of this report is to present the results of nine full-scale fire tests in a wide-body test article which utilized a cabin water spray system for the suppression of a postcrash aircraft fuel fire. The tests investigated the ability of two types of optimized spraying systems, each comprised of a series of spray zones with independent discharge activation within each zone based on zone temperature, at providing a level of protection equivalent to or better than a full cabin spray system, using a fraction of the water.

BACKGROUND.

The onboard cabin water spray program is comprised of several phases aimed at developing a safe and effective system for installation in a commercial transport aircraft (reference 1). Initial full-scale effectiveness tests were performed using the Safety Aircraft and Vehicles Equipment (SAVE), Limited, cabin water spray system. Although the SAVE system was found to offer an additional 2 minutes of escape time in both the narrow-body and wide-body fuselages under some fire scenarios, it was designed to spray water throughout the entire cabin and overhead for 3 minutes. This required 72 gallons of water in a typical narrowbody configuration and 195 gallons in the wide-body, which constituted a substantial weight penalty. Subsequent tests showed that the removal of the water spray from the cabin overhead area resulted in no significant reduction in the additional escape time offered by the system and reduced the stored water requirement by 8.6 percent (reference 2). Other tests showed the effectiveness of spraying water only in the cabin areas involved in fire, thereby further reducing the amount of water required (reference 3). Concurrent to these initial tests, a study was undertaken to address the various service considerations or "disbenefits" associated with an onboard water spray system. The results of these initial studies were factored into a benefit analysis to determine the potential for lives saved. Because the potential benefits of the system prevail over the disbenefits, a series of optimization tests were conducted in a narrowbody test fuselage to develop a system which would provide a level of protection equivalent to or better than the full spray system using a fraction of the water. The approach taken, as suggested by earlier test results, was to divide the full spray system into zones and spray water only where there was a fire or high temperatures, or "localizing" the spray, thereby enabling more effective use of the water. The zoning concept has been tested in the 707 narrow-body fuselage with favorable results; as much as 159 seconds of additional time available for escape can be achieved by using only 8 gallons of water (reference 4).

DISCUSSION

TEST DESCRIPTION.

Nine tests were conducted in a fully fire hardened DC-10 fuselage, which represented a typical wide-body, double aisle aircraft cabin. All tests employed a moderate amount of cabin interior materials in the vicinity of the fire door, consisting of five rows of fire blocked seats, honeycomb-type flat

interior panels used in the sidewall, ceiling, and storage bin areas, and carpet (figure 1). All tests utilized a standard 8- by 10-foot fuel pan adjacent to a type A door opening, with 55 gallons of JP-4 fuel used to create the pan fire. The fire was drawn into the fuselage by an exhaust fan mounted in the forward bulkhead, simulating a wind induced cabin draft.

Of the 9 tests conducted, 3 utilized the zoned system in which 21 gallons of water were sprayed; 1 test utilized 30 gallons of water. The zoned arrangement consisted of seven zones with 12 nozzles in each zone (figure 2). The zones were 8 feet in cabin length and included six spray nozzles mounted at the cabin periphery in each of the two boundary planes, with the spray discharge directed towards the center of the zone. Specifically, each nozzle was mounted perpendicular to the supply line and at a 45 degree angle with the vertical traverse plane (figure 3). An additional 3 tests were run using 21 gallons of water under a different nozzle configuration in which the zone size was reduced to half the original width, for a total of 10 zones (figure 4).

After an initial "shakedown" test in which the instrumentation and wind conditions were inspected (test 1), a test was run without introducing water spray into the cabin in order to establish "baseline" data (test 2). Following this, tests were conducted using 21 gallons and 30 gallons of water, respectively, (tests 3 and 4) at a nozzle flow rate of 0.23 gallons per minute (GPM). The next two tests used 21 gallons of water at a nozzle flow rate of 0.35 GPM and 0.50 GPM, respectively (tests 5 and 6). Additionally, three tests were conducted using 21 gallons of water at a nozzle flowrate of 0.35 GPM, but the nozzles were arranged in zones half the width of the previous tests, essentially allowing for spray activation on either side of the fuselage. Since the width of the DC-10 cabin was approximately 20 feet, it was believed that the zone size could be reduced in order to further decrease the amount of water spray required. During the first of the three half-zone tests, zones were activated when the temperature reached 300 °F as in previous tests (test 7). In an effort to further curtail water usage during the second test (test 8), the first zone was activated at 300 °F, but the remaining zones (secondaries) were not activated until the temperature reached 400 °F. Similarly, during the third test in this series (test 9), the initial zone was activated at 300 °F and the remaining zones were not activated until a temperature of 500 °F was reached. Table 1 summarizes the nine tests conducted.

The fuselage was outfitted with thermocouple trees, smoke meters, calorimeters, gas sampling stations and video cameras which monitored the conditions inside the cabin. Additionally, special sample tubes were placed at two locations which measured the amount of water vapor (figure 5). A description of the instrumentation follows.

<u>THERMOCOUPLE TREES</u>.

Eight thermocouple trees continuously measured the temperature throughout the cabin. The trees were located at 80, 220, 400, 580, 750, 940 (type A door opening), 1170, and 1420 inches from the forward bulkhead. Each tree consisted of eight thermocouple probes positioned from 1 foot above the floor to eight feet above the floor. The 8-foot location was approximately ceiling level.

Widebody
Water Spray Optimization
Test Summary

Test #	Nozzle Configuration	Nozzle Flowrate (GPM)	Water Quantity (GAL)	Activation Temp. (^{O}F) * Secondary	Test Duration (MIN)	Comments
1					5:15	"Shakedown Test" Instrumentation Check
2					4:30	"Baseline Test" No Water Spray
3	7 full-zones	0.23	21	300^{O} F	5:00	Determine Effect of Save Nozzle in Zoned Configuration
4	7 full-zones	0.23	30	300^{O} F	5:00	Determine Effect of Longer Discharge Duration
5	7 full-zones	0.35	21	300^{O} F	5:00	Determine Effect of Higher Flowrate Nozzle
6	7 full-zones	0.50	21	300^{O} F	5:00	Determine Effect of Higher Flowrate Nozzle
7	10 half-zones	0.35	21	300^{O} F / * 300^{O} F	5:00	Determine Effect of Greater Number of Smaller Zones
8	10 half-zones	0.35	21	300^{O} F / * 400^{O} F	5:00	Determine Effect of Varying Activation Temperature
9	10 half-zones	0.35	21	300^{O} F / * 500^{O} F	5:00	Determine Effect of Varying Activation Temperature

Table 1

SMOKE METERS.

Smoke meter (light transmission) stations were located at 80, 340, 580, and 1280 inches from the forward bulkhead. Each station contained three smoke meters positioned at 18, 42, and 66 inches from the floor level. The smoke meters consisted of a collimated light source and photocell separated by 1 foot.

GAS ANALYSIS.

Continuous gas sampling stations used to measure carbon monoxide, carbon dioxide, and oxygen were located at 80 and 580 inches from the forward bulkhead. Each station had intakes at 42 and 66 inches from the floor.

CALORIMETERS.

Calorimeters were used to measure the heat flux at four locations: 80, 580, 940, and 1280 inches. The transducers were all mounted at a height of 42 inches along the fuselage centerline. At stations 80 and 580 the transducers were facing aft; at station 1280, the transducer was facing forward. The transducer located at station 940 was facing directly toward the fire door.

WATER VAPOR ANALYSIS.

Specialized collection tubes were used to collect water vapor samples during the tests. Twelve collection tubes were mounted horizontally through the front face of a sample box containing an ice-water bath, with two of the twelve collection tubes serving as controls. An internal filter was positioned within each tube far enough from the ice-water bath to prevent condensation of water in the filter. The interior ends of the ten sample tubes were attached to separate calibrated vacuum lines which passed through the bottom of the sample box and led to an array of ten solenoid valves. The lines join downstream of the solenoid valves and lead to a rotameter which is connected to a vacuum pump. The solenoid valves are automatically controlled such that samples are sequentially drawn for 30 seconds each during the 5-minute test. Two sampling stations were used during the tests, one located at station 80 at a height of 5 feet 6 inches, and another at station 580 at a height of 3 feet 6 inches. A detailed description of the method of collection and analysis can be found in reference 5.

TEST RESULTS

The following analysis compares the results of the tests based on temperature profiles, gas concentrations, and smoke levels within the cabin. In order to determine the effect the various hazards have on survivability, a fractional effective dose (FED) model was used to calculate the survival time at two forward locations within the cabin. The recently developed model utilizes the best available data to determine the incapacitation of humans subjected to heat and toxic combustion gases. It assumes that the effect of heat and each toxic gas on incapacitation is additive. The model also assumes that the increased respiratory rate due to elevated levels of carbon dioxide is manifested by enhanced uptake of other gases (reference 6).

In addition, the increase in survival time offered by using the zoned water spray arrangement is compared on the basis of quantity of water used to determine which combination offers the greatest improvement in survivability per gallon of water sprayed.

TEMPERATURE PROFILES.

Figure 6 shows the temperature at 4 feet above floor level at station 80. As indicated, there is a significant reduction in cabin air temperature during the various flow rate zoned water spray tests in comparison to the baseline test, but there is minimal temperature difference among the three water spray tests at this location. Similarly at station 400, the temperatures are nearly interchangeable at both the 3 and 5 foot levels for the 0.23, 0.35, and 0.50 gallon per minute (GPM) nozzle flow rate zoned tests (figure 7). A test was conducted using 30 gallons of water at the 0.23 nozzle flow rate to determine the benefits of a marginal increase in water spray discharge. As shown in figure 8, the additional 9 gallons of water spray yields somewhat lower temperatures at the 4 foot level at stations 220 and 750.

Due to the considerable fuselage width of wide-body transport aircraft, it was believed that a considerable water savings could be recognized by dividing the spraying zones in half, thereby enabling more effective application of the limited water supply. As mentioned previously, three additional tests (7,8,and 9) were conducted under this spray configuration, all of which used an identical nozzle flow rate of 0.35 GPM. This nozzle type provided the optimal nozzle flow rate in the narrow-body test article (reference 4). As shown in figure 9, of the three half zone tests, the temperatures were lowest when the initial spray zone was activated at 300 °F and the remaining zones were not activated until 500 °F was reached (test 9).

GAS ANALYSIS.

Figures 10 through 18 represent the gas levels of carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) at two forward locations within the cabin. Figures 10 and 11 show the CO concentration between 3 feet 6 inches and 5 feet 6 inches above floor level at station 580 for the 0.35 and 0.50 GPM flow rate full-zoned tests, respectively. Both figures display the concentration of CO during the baseline test at this location for comparison. Figure 12 displays the CO concentrations of these two tests (0.35 and 0.50 GPM flow rate zoned) along side one another. As shown, the level of CO was marginally lower during the 0.35 gpm test, supporting results obtained during the narrow-body optimization tests in which this nozzle flow rate consistently yielded the lowest levels of CO. One reason for this is the duration of water spray; the 0.35 GPM flow rate nozzles sprayed for approximately 20 seconds longer than the 0.50 GPM nozzles during the full-zoned tests, and thereby controlled the ignition of materials and production of combustion gases more effectively. Figure 13 displays the levels of CO at the most forward cabin location (station 80, between 3 feet 6 inches and 5 feet 6 inches above the floor) for the baseline test and two half-zone tests. Of the two half-zone tests, (both of which utilize a nozzle flow rate of 0.35 GPM), the test in which the secondary zones are not activated until the temperatures reach 500 °F ultimately yields a lower level of CO. This can again be attributed to the duration of the water spray; although the two tests utilize identical spray

patterns, nozzle flow rate, and water quantity, the delay in activation of the secondary zones during test 9 provides an additional 30 seconds of spray duration, thereby yielding slightly lower gas concentrations. This comparison was also made for tests 8 and 9 (figure 14). Again, delaying water spray activation produced a slight lowering in the CO concentrations. As shown in figure 15, the level of CO_2 between 3 feet 6 inches and 5 feet 6 inches was reduced considerably during the 0.35 GPM zoned test. Figure 16 displays the levels of CO_2 at a height of 5 feet 6 inches during the two full- zone tests, three half-zone tests, and baseline test. As indicated, the lowest levels occurred during the 0.35 GPM flowrate full-zone test and the half-zone test in which secondary zones were activated at 500 °F. As was the case with the CO production, the higher flow rate full-zoned test (test 6) generated slightly lower levels of CO_2 in the early part of the test, but due to the shorter spray duration allowed the gas concentration to climb higher than the 0.35 GPM flow rate full-zoned test after 2 minutes and 30 seconds.

The depletion of oxygen within the cabin parallels the production of CO and CO_2 for all tests in a nearly identical manner (figures 17 and 18). As indicated in figure 18, the least amount of oxygen depletion occurred during tests 5 and 9, as expected.

SMOKE LEVELS.

Figures 19, 20, and 21 compare the levels of light transmission between the baseline test and tests 5, 7, and 9, respectively, between a height of 1 foot 6 inches and 3 feet 6 inches above floor level at station 340. As indicated, all three of these tests offer a significant increase in light transmission (and hence, visibility) over the baseline test. Figure 22 displays the percentage of light transmission for several of the tests at a height of 1 foot 6 inches at station 340. Of all the tests, the light transmission is highest during the half-zone test (test 9) from the beginning until 3 minutes and 30 seconds into the test. From this point on, the light transmission is the greatest during the full-zone test using a nozzle flow rate of 0.35 GPM (test 5). The light transmission during test 6 was only slightly lower than test 9 from the beginning until 3 minutes and 30 seconds, and was only slightly lower than test 5 from this point until test termination. (During optimization tests conducted in the narrowbody, there was a direct correlation between the duration of spray and light transmission, with the most light transmission resulting from the shortest duration of spray; this occurred when a 0.50 GPM flow rate nozzle was used with 8 gallons of water). Although test 6 did not produce the highest instantaneous level of light transmission, the average was likely to be the highest of all the tests.

WATER VAPOR CONCENTRATIONS.

Water vapor was measured at station 80, 5 feet 6 inches from the floor and at station 580 at 3 feet 6 inches above the floor for tests 2 through 8. Water vapor concentations were reported as volume percent water vapor in air (volume water/volume of mixture). Figures 23 and 24 represent the water vapor concentration as a function-of-time for these sampling locations. As shown, the concentrations of water vapor reached as high as 17 percent for the baseline test at station 80, 5 feet 6 inches, and slightly lower at station 580, 3 feet 6 inches, reaching a maximum of 14 percent. The water vapor

generated in the baseline test was a product of the burning interior materials and JP-4 fuel combustion.

As shown in the figures, the concentrations of water vapor as a function-of-time for the water spray tests were similar to that of the baseline test. The water vapor generated during water spray tests was a product of both combustion and of vaporization of the fine water mist. Since the water spray delayed the temperature rise in these locations and the concentration time curves were similar for baseline and water spray tests, the total thermal survival hazard was reduced during the water spray tests at these locations.

Figures 25 and 26 represent the water vapor concentration as a function-of-cabin-temperature at the two sampling locations (the concentration of water at its dew point is indicated by the heavy pink line, the baseline water concentration by the heavy black line). These figures indicate that for temperatures greater than 150 °F, the contribution of the vaporization of water to the total water vapor content (of the air) is about the same as the contribution of the combustion products. It can also be seen from these figures that the water vapor concentration for all tests is far below the dew point concentration.

FRACTIONAL EFFECTIVE DOSE.

Figures 27 through 30 indicate the theoretical survival times at two locations in the forward cabin as calculated by the fractional effective dose (FED) model. All figures show the baseline FED for comparison. As shown in figure 27, the 0.35 GPM full-zone test yields a marginal increase in survival time over the higher flowrate 0.50 GPM full-zone test at station 580. At this location, conditions became nonsurvivable (FED=1) in 213 seconds during the baseline test; by spraying water in the full-zone arrangement, survival was extended to 299 seconds using the 0.50 GPM nozzle, and 309 seconds using the 0.35 GPM nozzle. Similarly at station 80, 3 feet 6 inches above floor level (figure 28), nonsurvivable conditions were also reached in 213 seconds during the baseline test; conditions became non-survivable in 316 and 324 seconds during the 0.50 GPM and 0.35 GPM full-zoned tests, respectively. These trends are consistent with those obtained during narrowbody testing done previously.

Figure 29 presents the survival times for the half-zone tests at station 80, 5 feet 6 inches from the floor. As shown, conditions during the baseline test became nonsurvivable in 196 seconds. By activating all zones at 300 °F, survivability was increased 55 seconds to 251; when the secondary zones were not activated until 400 °F an additional 41 seconds was recognized, but by delaying secondary zone activation until 500 °F was reached, 70 additional seconds of survivability were gained.

It is interesting to note that the conditions within the cabin became nonsurvivable earlier at station 80 (which is actually more remote from the fire hazard) than at station 580 during the baseline test. This can be explained by the arrangement of the test article. In order for the fire to be drawn into the fire door with enough penetration to simulate a wind enhanced condition, all cabin doors were closed. Under these conditions, the combustion products progressed to the forward bulkhead, where the exhaust fan is positioned. The smoke and gases tend to accumulate in the forward area of

the cabin, resulting in elevated levels of the toxic gases, ultimately reducing survivability (the survivability is driven primarily by the CO concentration during all tests).

In figure 30, the survivability of the 0.35 GPM flow rate full-zoned test (test 5) is compared to that of the half-zone test in which secondary zones were activated at 500 °F (test 9), since these tests produced the most favorable results. During test 5, the conditions became nonsurvivable in 309 seconds at station 580, or 96 additional seconds over the baseline test. The half-zone configuration provided 103 seconds of additional escape time, or 316 seconds until nonsurvivable conditions are reached.

In an effort to quantify the effectiveness of the water spray during the various zoned tests, a bar graph was generated that compared the additional seconds of escape time per gallon of water sprayed ("seconds per gallon" or SPG) for each of the tests (figure 31). This determined which spray configuration produced the greatest survivability for a specific quantity of water. Figure 32 displays the calculations that were performed to develop the data point for each test. Of the seven water spray tests conducted, the half-zone test with 500 °F secondary zone activation yielded the most survivability per gallon of water sprayed (test 9). These results are based upon survivability considerations at a particular cabin location and height (in this example at station 580, 3 feet 6 inches from the floor).

SUMMARY OF RESULTS

In general, there exists a direct correlation between the amount of water sprayed and the cabin air temperature (i.e., for a given nozzle flow rate, the greater the quantity of water sprayed, the lower the temperature, as demonstrated during tests 3 and 4). As expected, temperatures were lower during test 4 than in test 3 due to the greater quantity of water sprayed (30 gallons versus 21 gallons). The primary mechanisms responsible for the direct correlation between cabin air temperature and quantity of water sprayed is the result of the water spray's ability to reduce the burning rate of the materials and cooling of the smoke layer for a greater length of time during the higher quantity spray tests. This was demonstrated during earlier narrow-body tests and confirmed in this series of wide-body tests. Although there were only slight differences in temperatures between the various flow rate nozzle tests when the quantity of water sprayed was equivalent, the temperatures were clearly lower at the forward end of the cabin during half-zone test No. 9. During this test, secondary zones were not activated until 500 °F; this provided a slight delay in spray activation in secondary zones, thereby allowing the water spray to continue longer during the latter part of the test, when it was most needed.

There was also a correlation between the duration of the water spray and the amount of toxic gases produced. A comparison of tests 5 and 6 reveals slightly lower levels of CO and CO_2 and less oxygen depletion when the 0.35 GPM flow rate was used. By spraying at this flow rate, the spray duration was 20 seconds greater than with the 0.50 GPM flow rate. This also occurred during the half-zone tests. Test 7 (300 °F secondary zone activation) yielded the highest levels of CO at the forward end of the cabin; test 8 (400 °F

(500 °F secondary zone activation) the lowest levels of CO occurred. As mentioned above, the delay in activation of secondary zones allowed for the water spray to continue until nearer the end of the test, when it had more of an impact.

In terms of light transmission, all full-zone and half-zone tests provided a marked increase over the baseline test. During test 9, the light transmission was clearly the highest of all tests from commencement until 3 minutes and 30 seconds. From this point until termination, however, the two full-zone tests provided slightly higher levels of light transmission. It appears that the delay in secondary zone activation experienced during the half-zone test allowed the smoke to restratify better in the early part of the test, causing a slight increase in light transmission. Conversely, restratification of the smoke layer was not as great during the early part of the full-zone tests because there was a greater number of zones activated, and hence, more water being sprayed. This could have caused slightly greater turbulence and mixing, the reason that there was a higher level of smoke at the early juncture of the full-zone tests.

An investigation of the water sampling data revealed that the water spray presented no additional thermal hazard. Because the water spray delayed the temperature rise at the sampling locations, and the concentration time curves were similar with and without water spray, the total thermal survival hazard was reduced.

CONCLUSIONS

As shown in earlier narrow-body optimization tests and confirmed throughout this series of tests in the wide-body fuselage, the best technique for maximizing water spray usefulness is to divide the system into zones, allowing for better control of the water spray and thereby minimizing the waste. By dividing the zones in half at the symmetry plane, the effectiveness of the water spray can be increased even further, providing additional seconds of escape time over the full-zone arrangement. Both full- and half-zone configurations support the earlier findings of increased visibility over a system which sprays throughout the entire cabin, because of restratification of the smoke and gas layer in the areas of the cabin that are more remote from the fire origin.

It was also determined that by delaying activation in the secondary zones (other than initial zone) until a higher predetermined temperature was reached, a greater majority of the available water could be applied where it was most needed, in the area of the initial fire. This method also allowed for the spray to continue until the latter part of the test, when it appeared to have more of an impact. This was demonstrated during test 9, which generated the longest survivability at station 580 with 316 seconds. This was an increase of 103 seconds of survivability over the non-spray test, or 4.9 seconds of additional escape time per gallon of water used. At this rate, 8-12 gallons of water could theoretically provide as much protection as seat fire blocking (40-60 second improvement in survival time).

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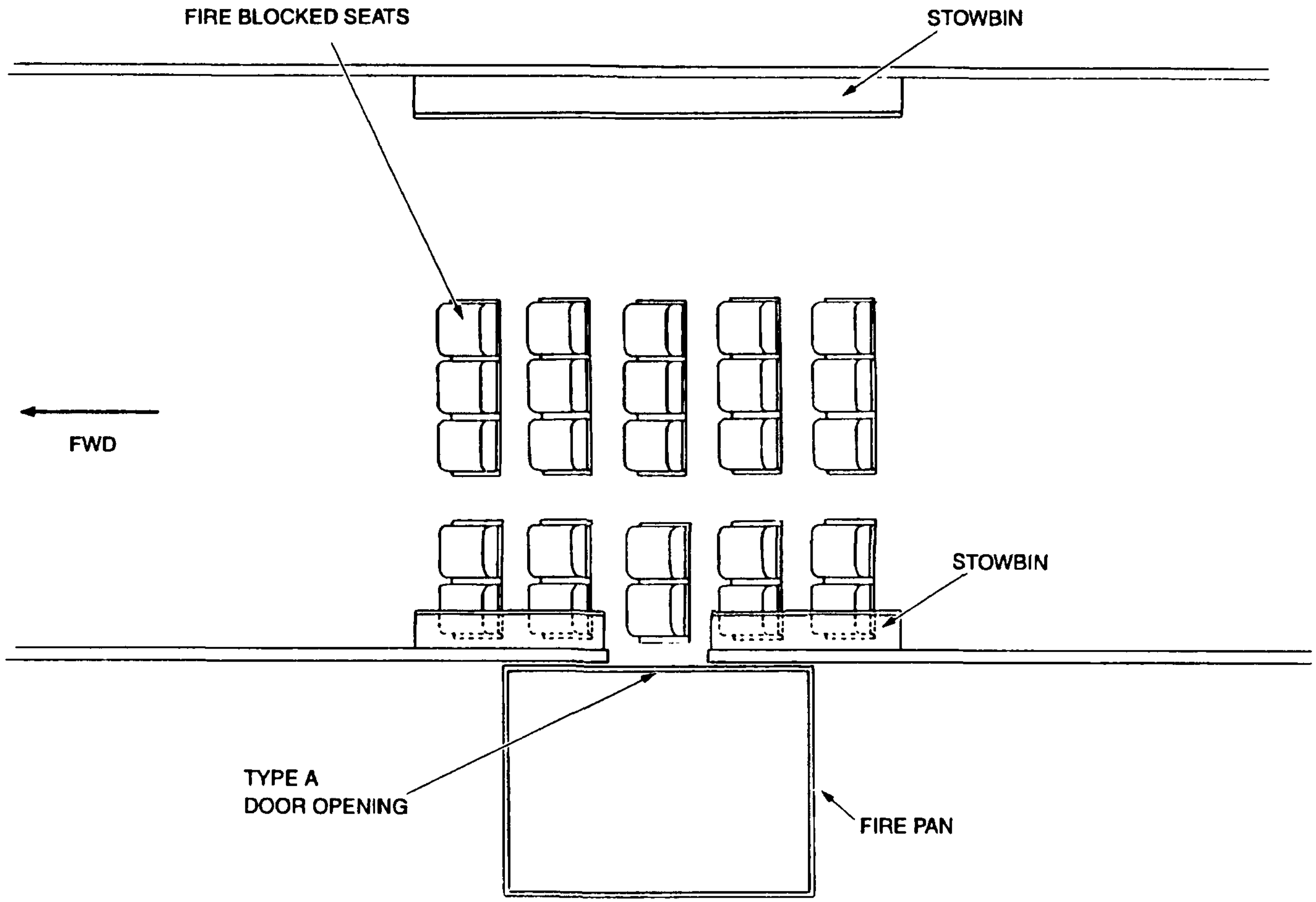


FIGURE 1. CABIN CONFIGURATION

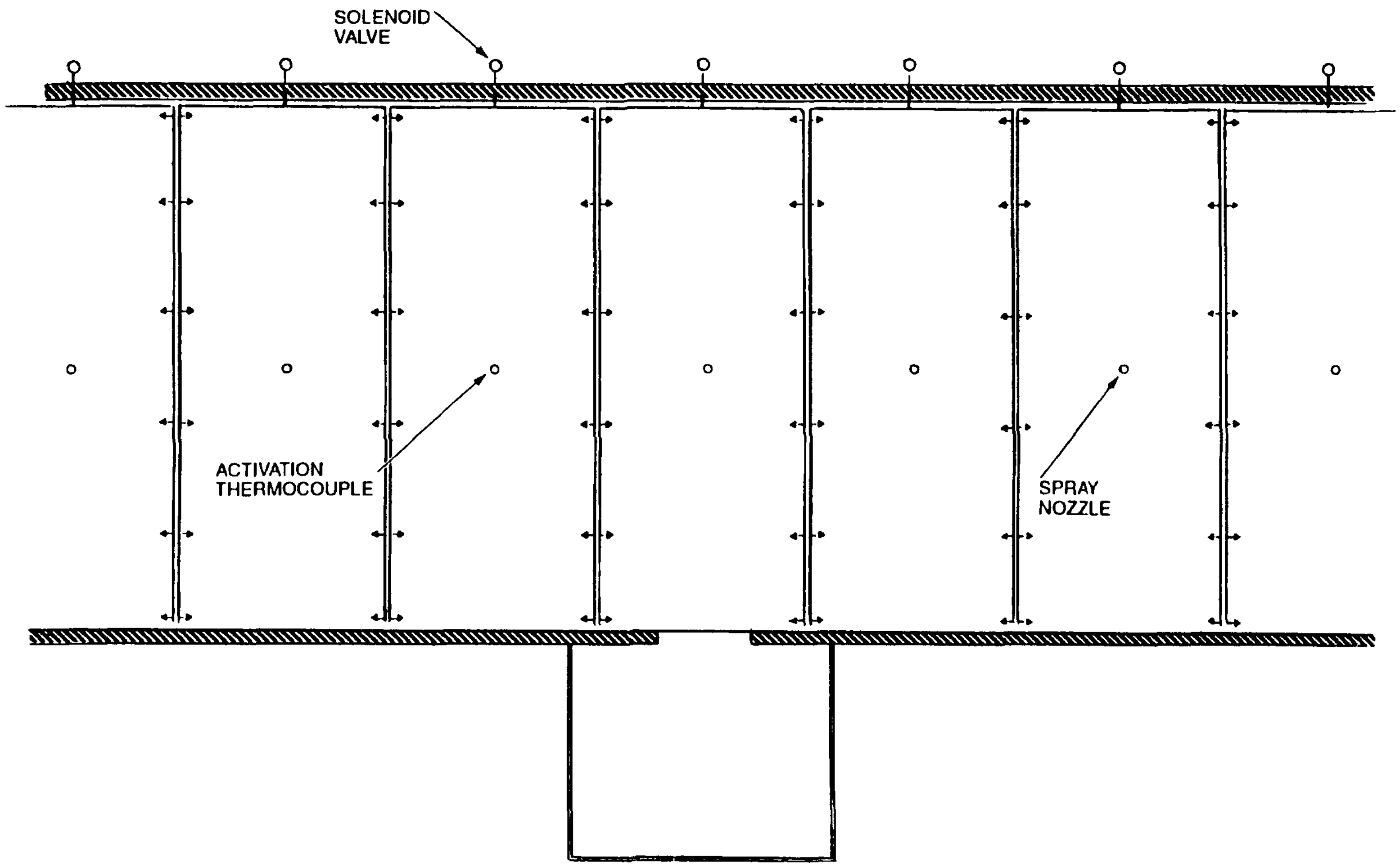


FIGURE 2. TC-10 ZONED WATER SPRAY SYSTEM

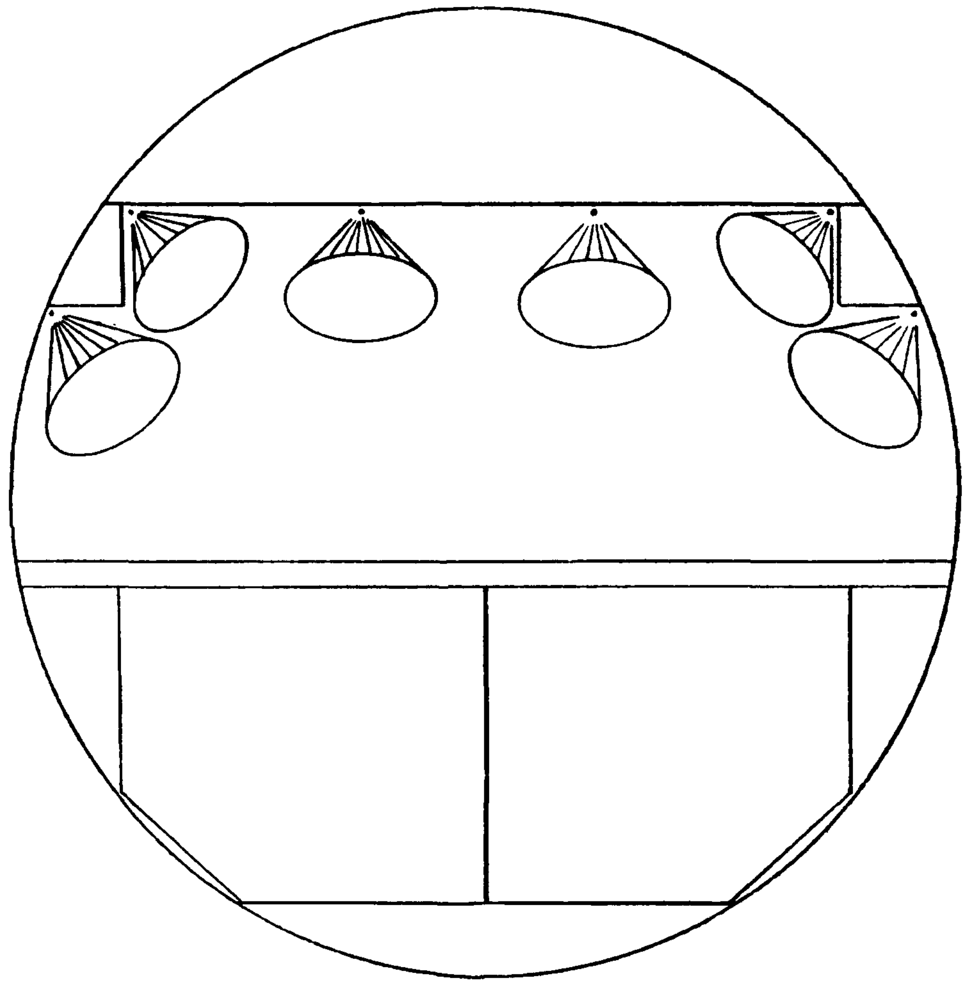


FIGURE 3. TC-10 ZONED WATER SPRAY SYSTEM

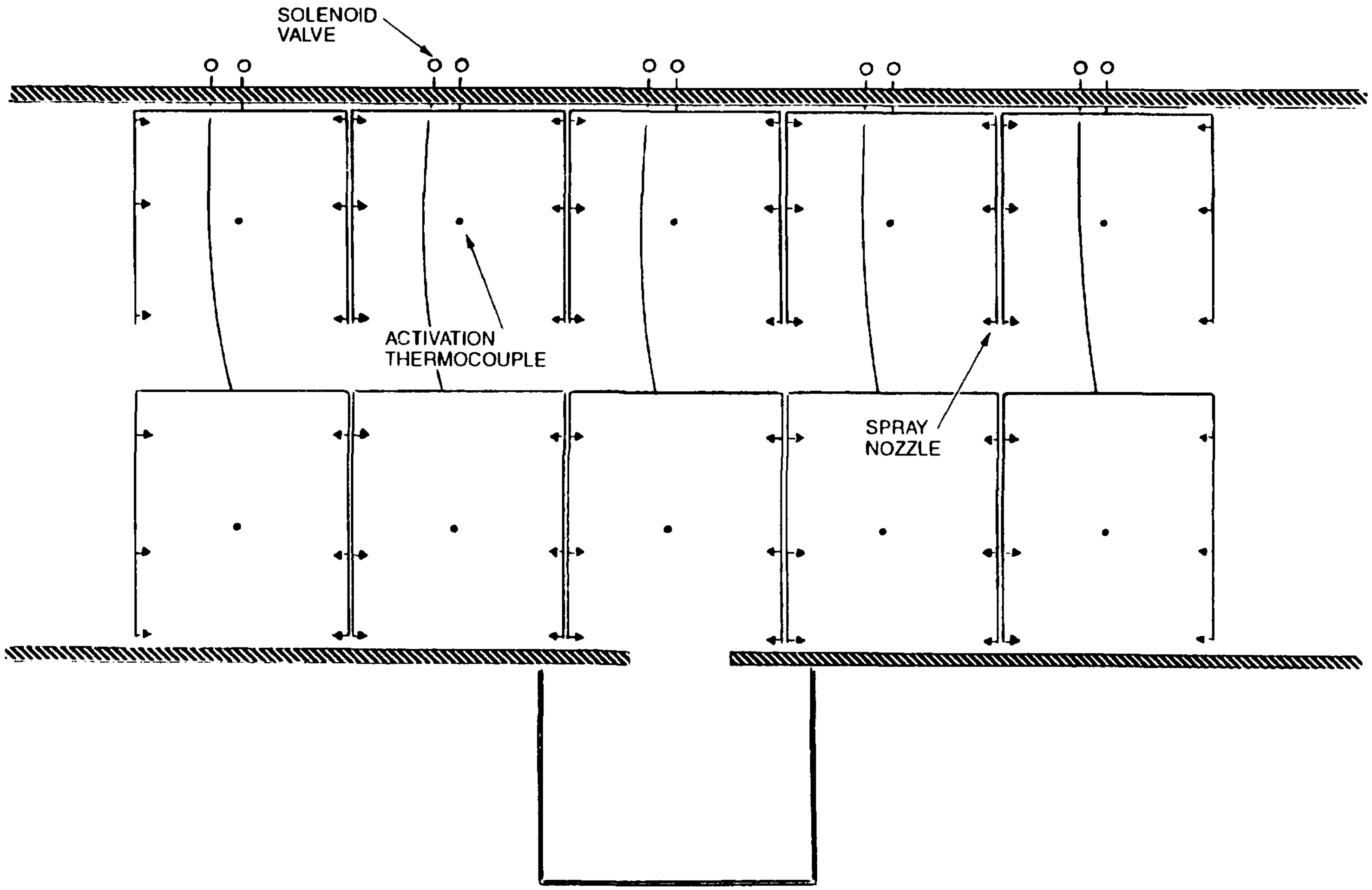


FIGURE 4. "SPLIT ZONE" WATER SPRAY STSYEM

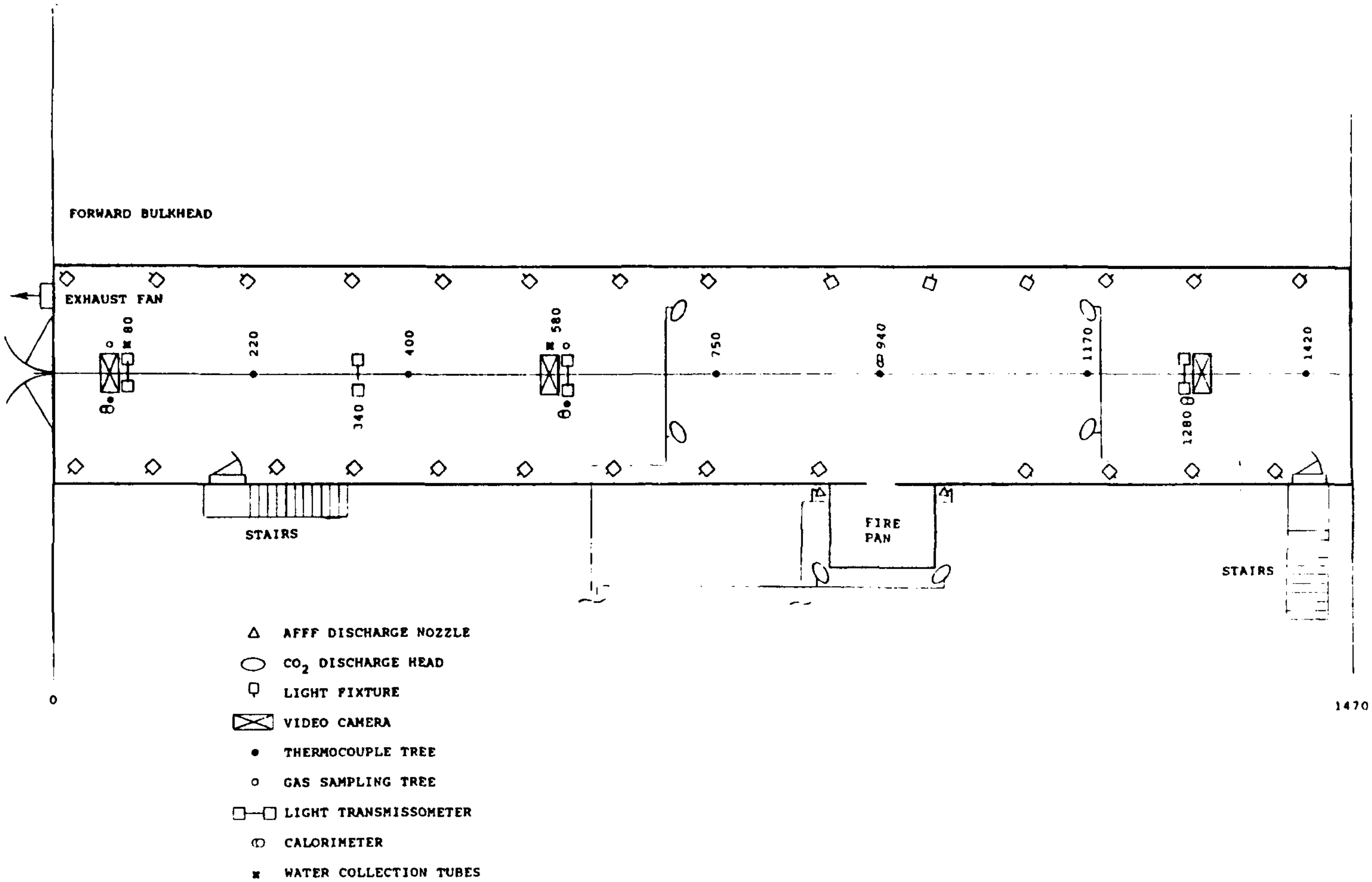


FIGURE 5. TC-10 TEST CONFIGURATION

FIGURE 6. TEMP @ STA 80, 4'

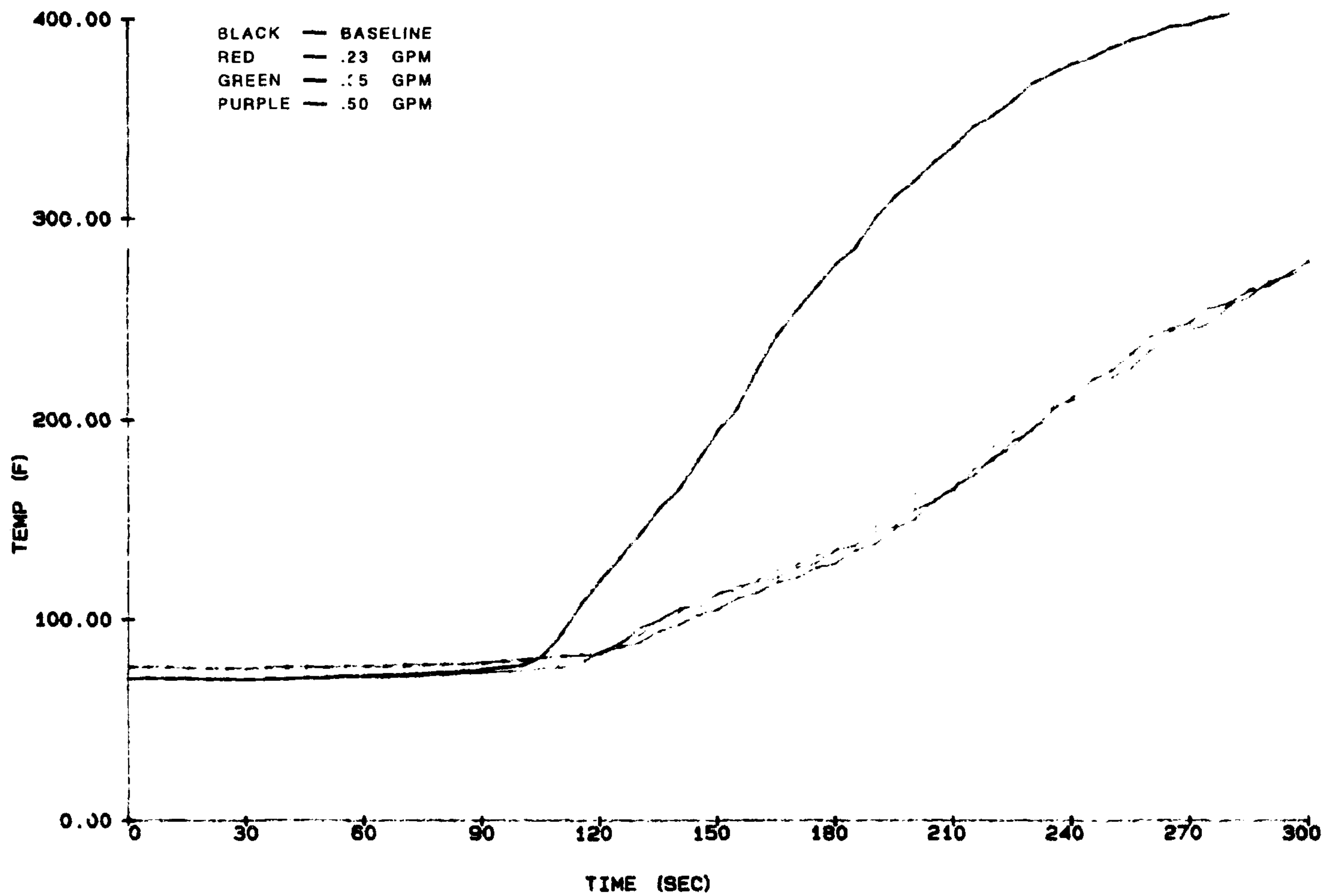


FIGURE 7. TEMP @ STA 400, 3' AND 5'

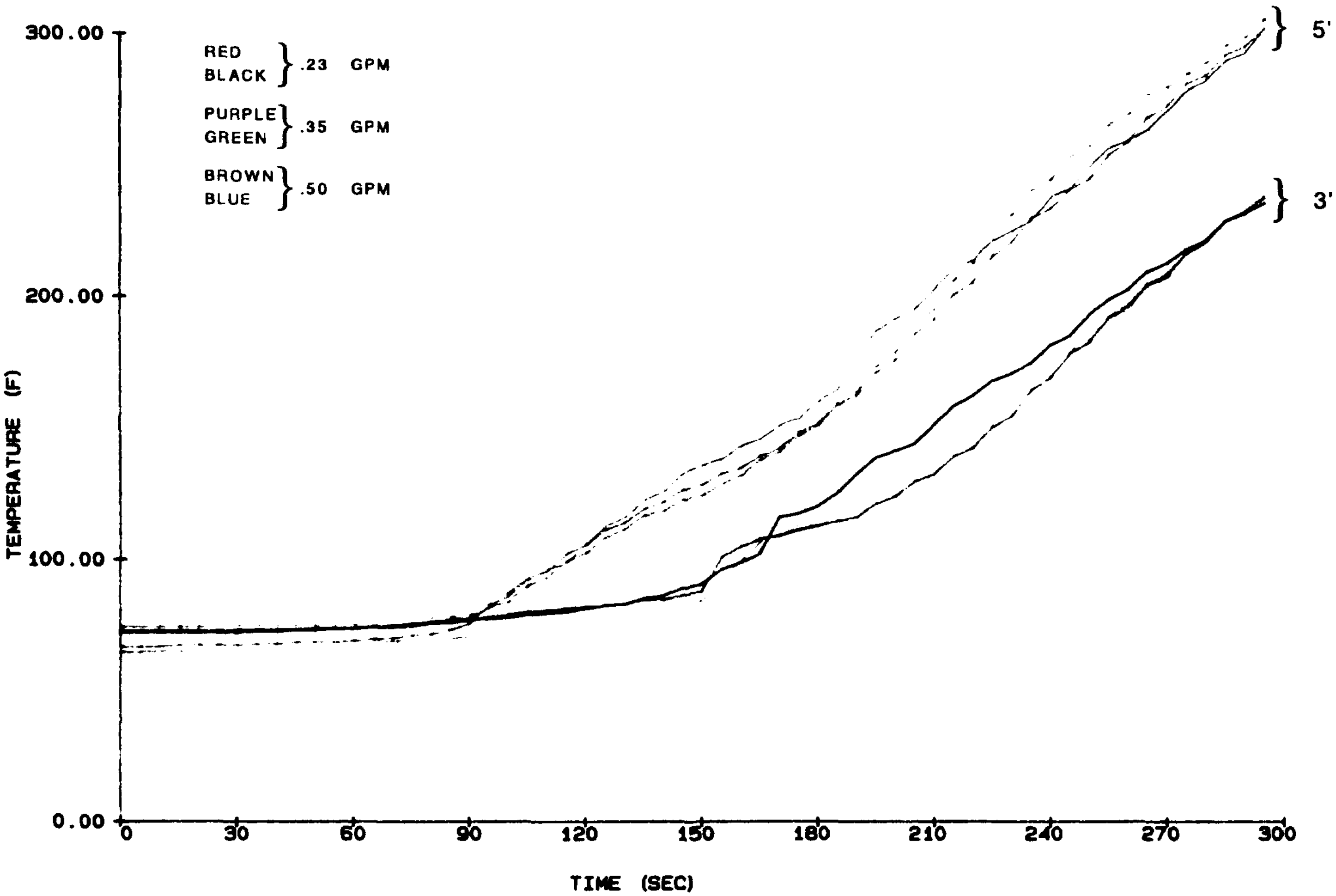


FIGURE 8. TEMP @ STA'S 220 AND 750, 4'

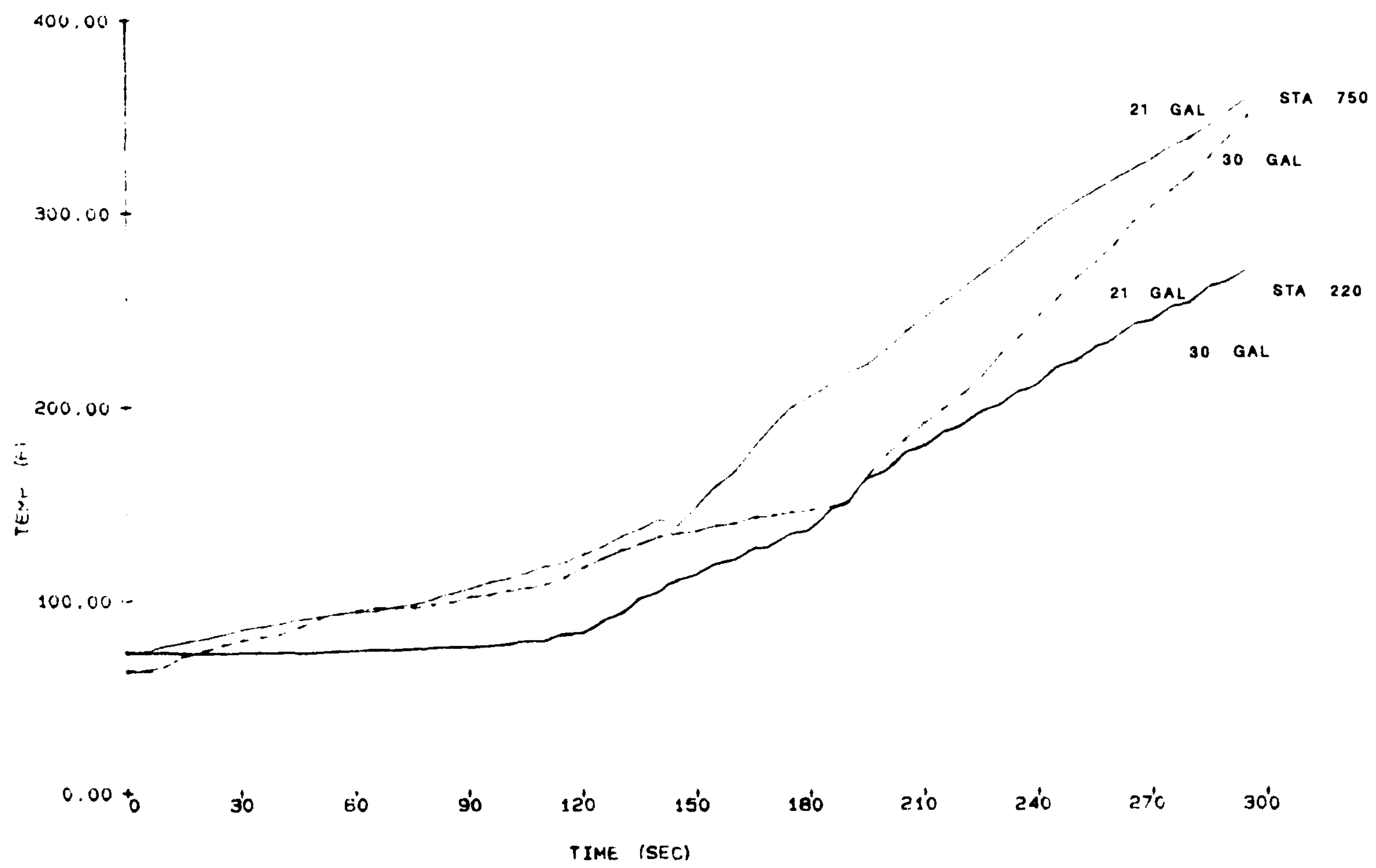


FIGURE 9. TEMP @ STA 80, 4'

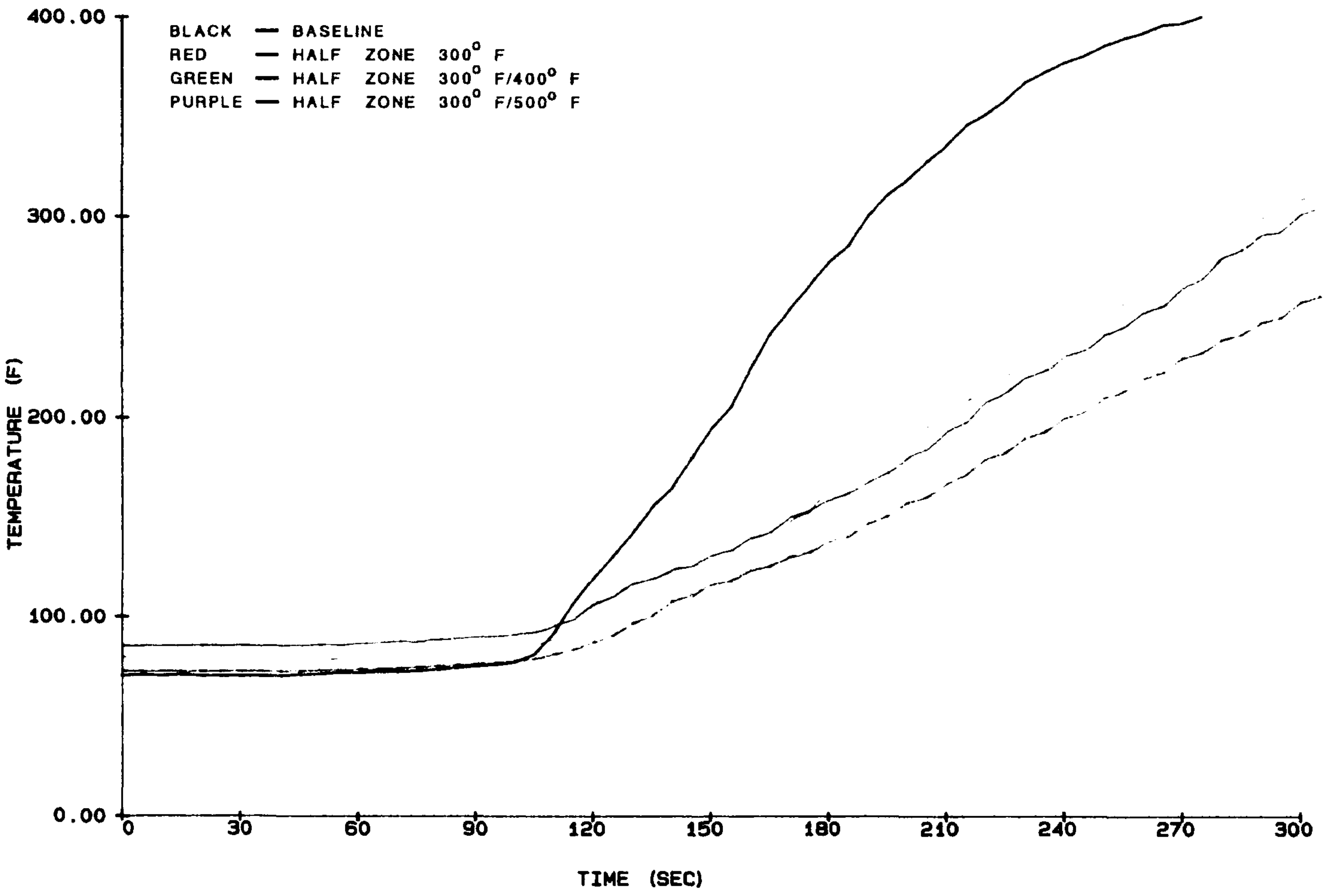


FIGURE 10. CO @ STA 580, 3'6" TO 5'6"

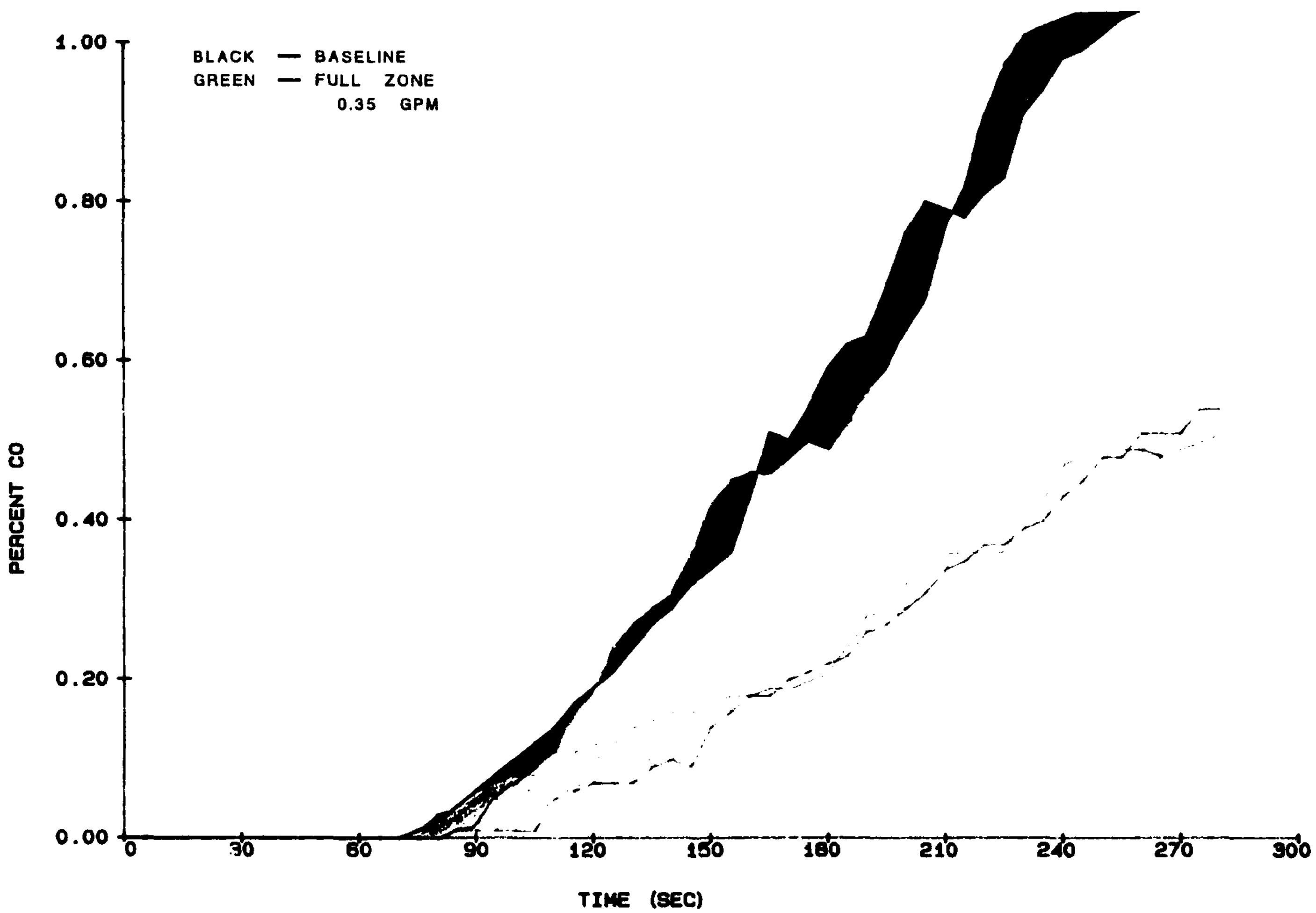


FIGURE 11. CO @ STA 580, 3'6" TO 5'6"

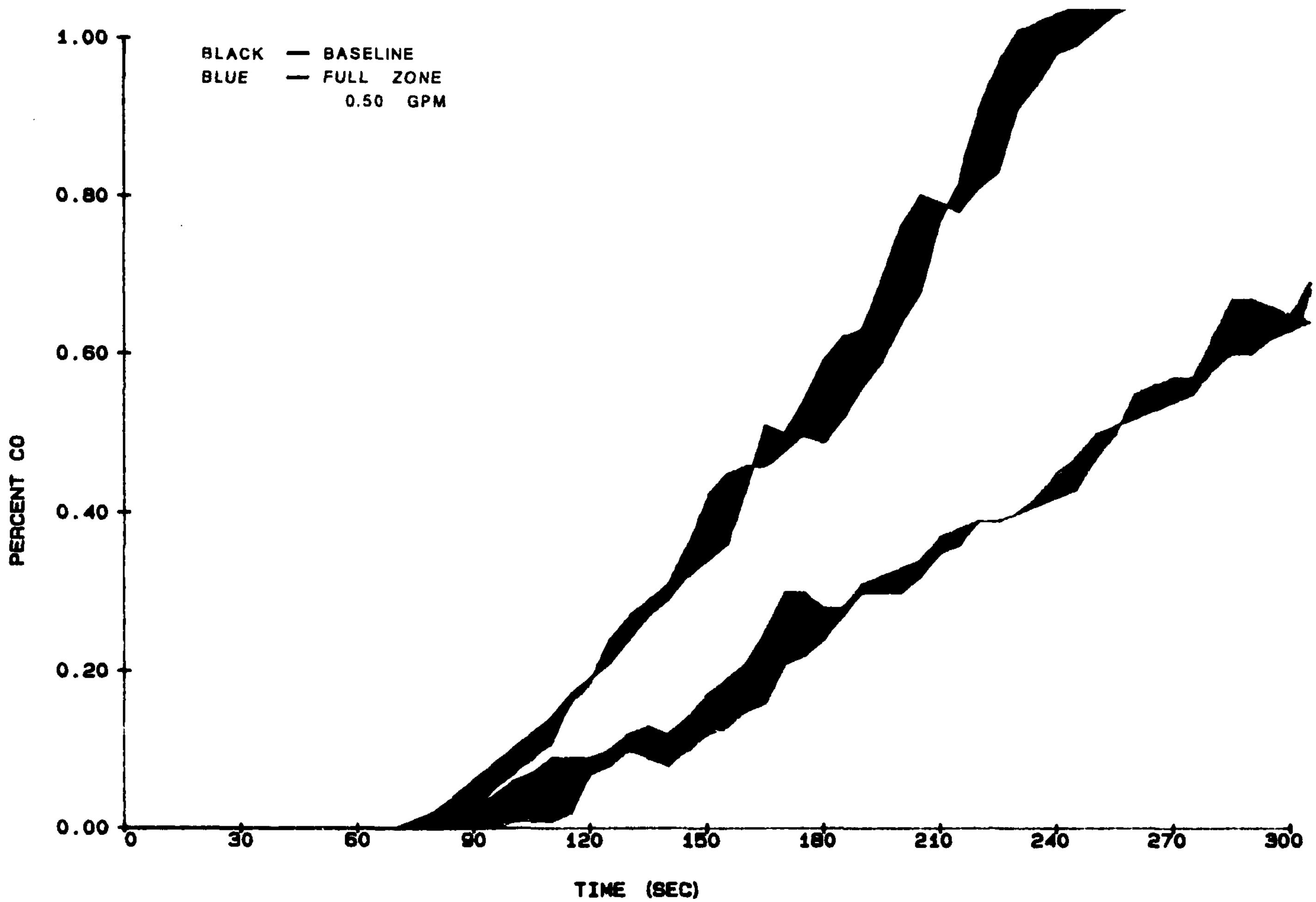


FIGURE 12. CO @ STA 580, 3'6" TO 5'6"

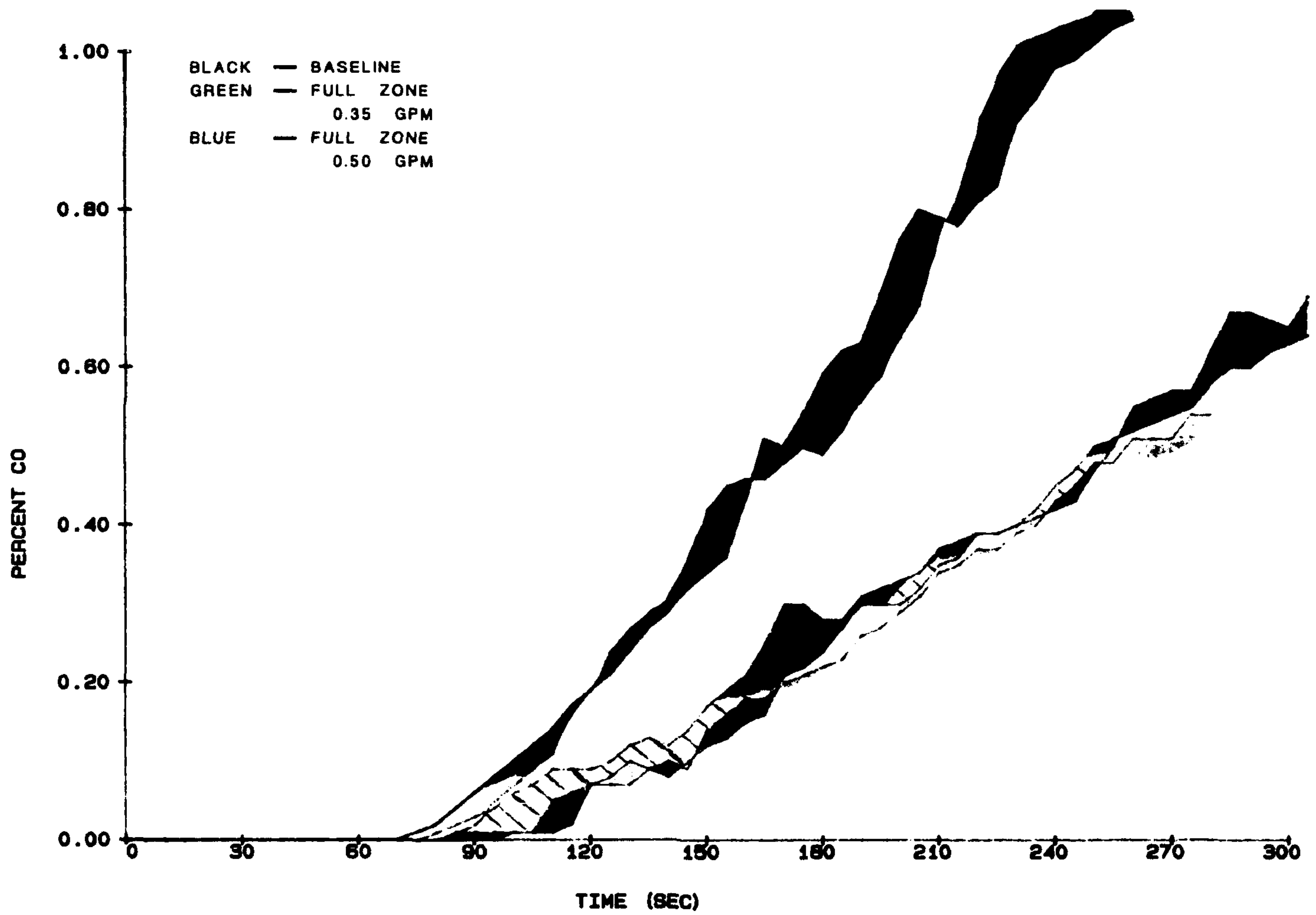


FIGURE 13. CO @ STA 80, 3'6" TO 5'6"

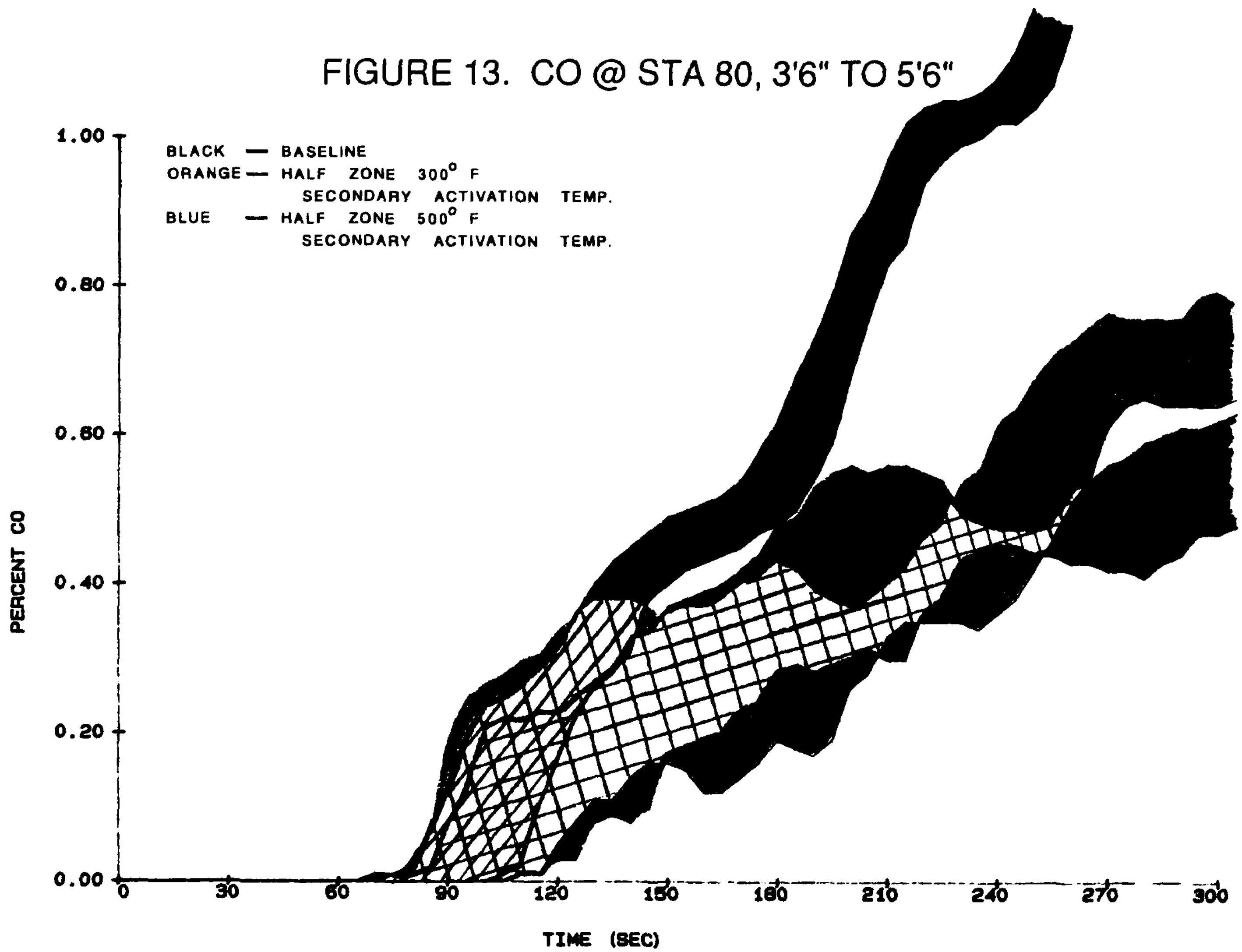


FIGURE 14. CO @ STA 80, 3'6" TO 5'6"

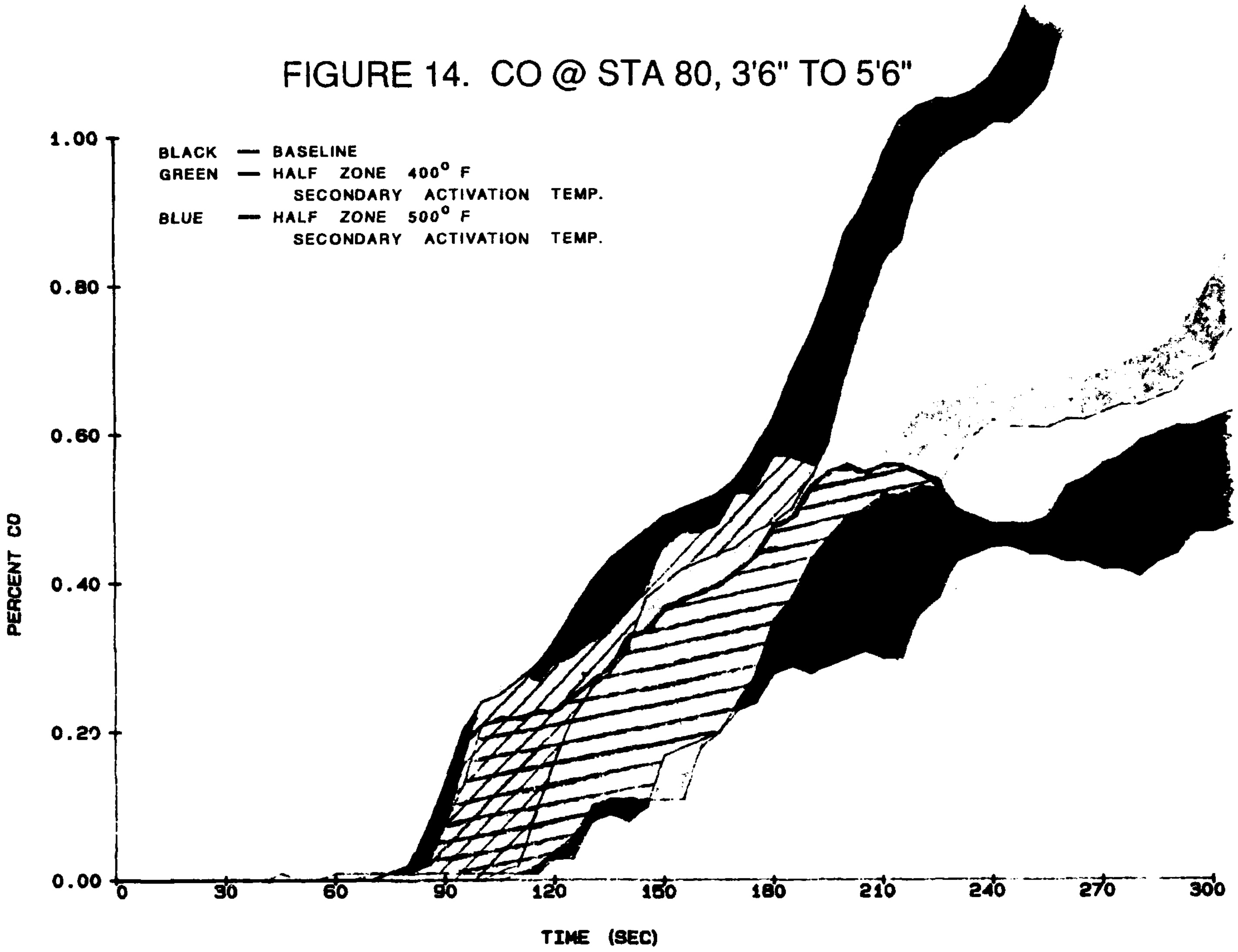


FIGURE 15. CO2 @ STA 580, 3'6" TO 5'6"

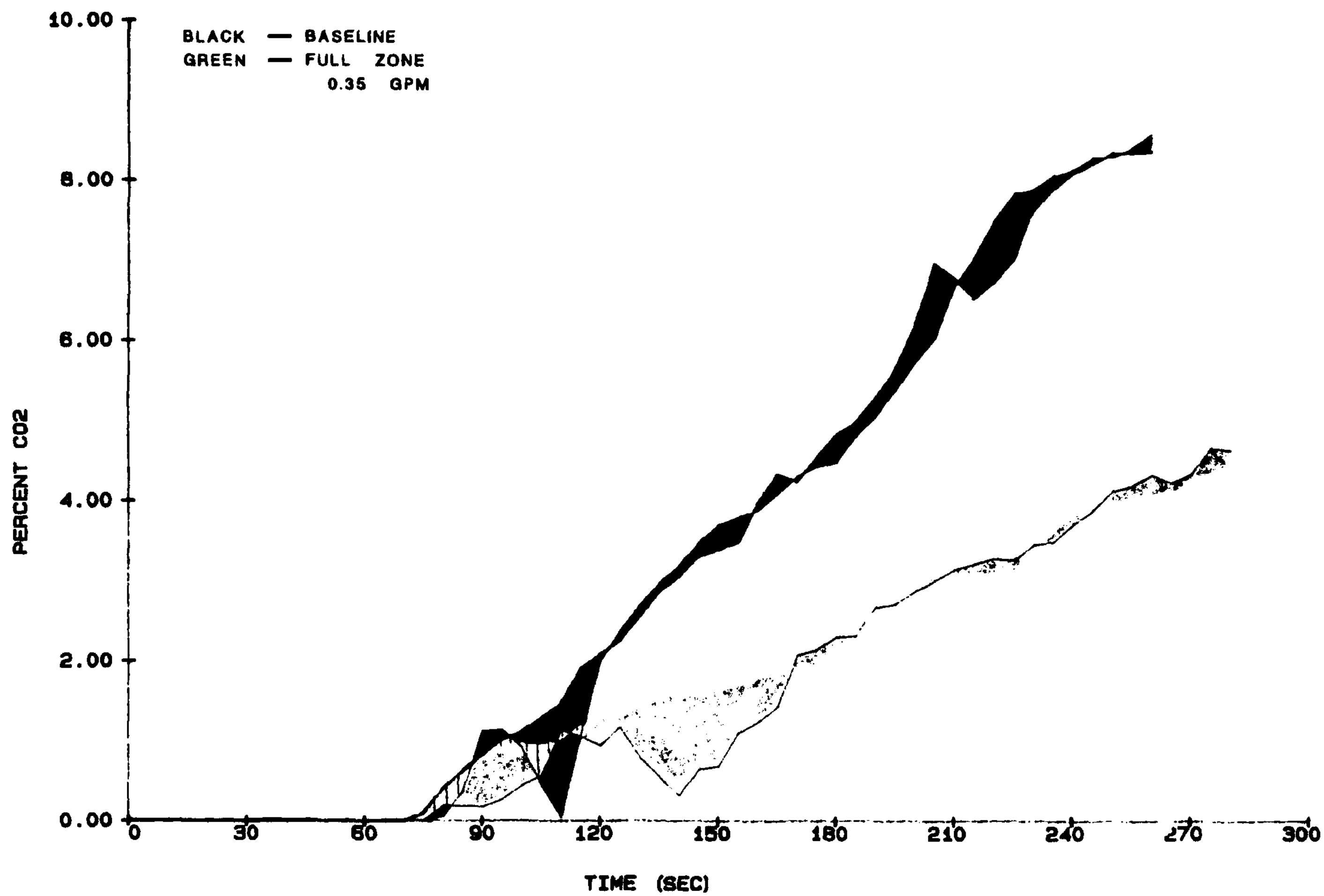


FIGURE 16. CO_2 @ STA 580, 5'6"

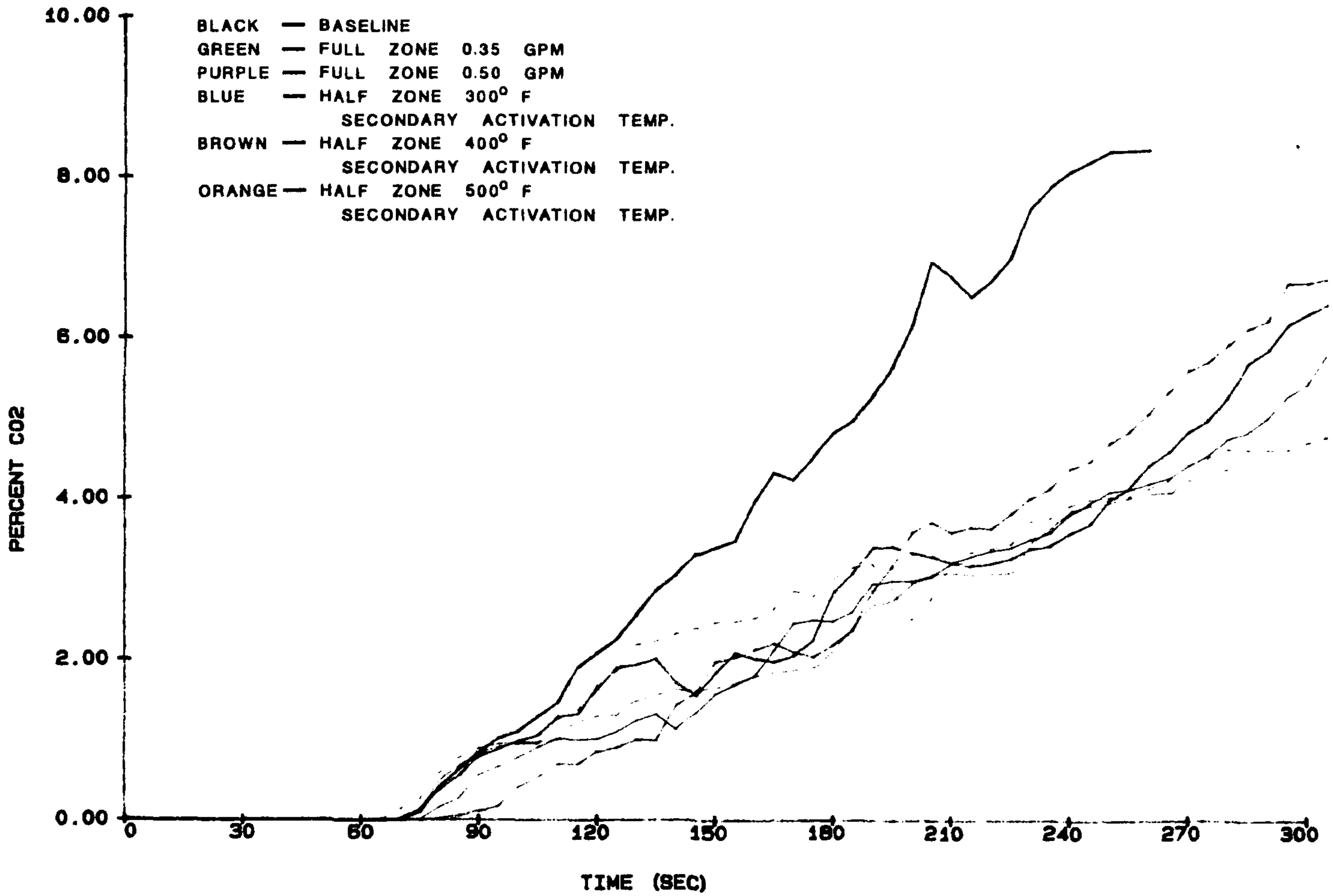


FIGURE 17. 02 @ STA 80, 3'6" TO 5'6"

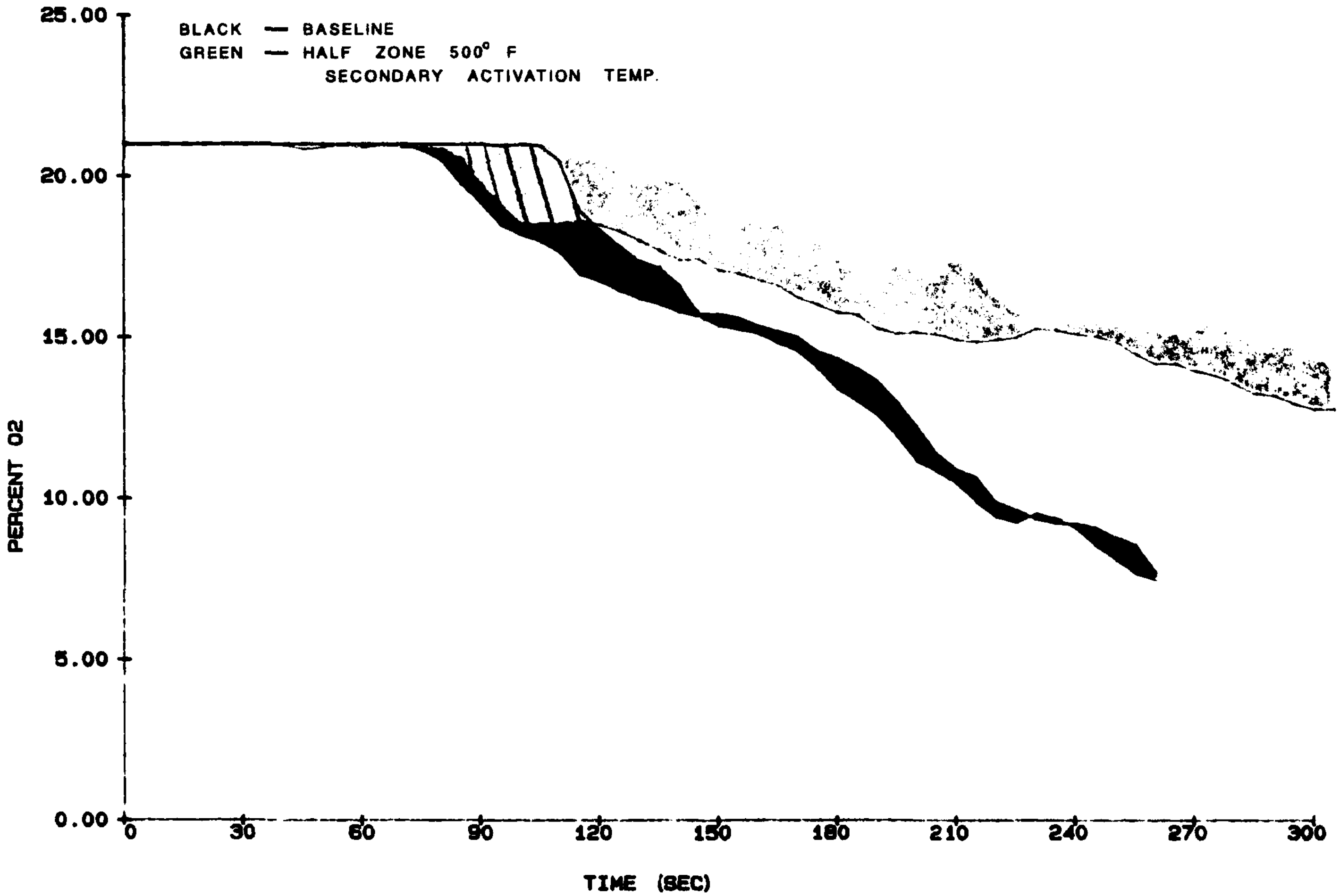


FIGURE 18. O2 @ STA 80, 5'6"

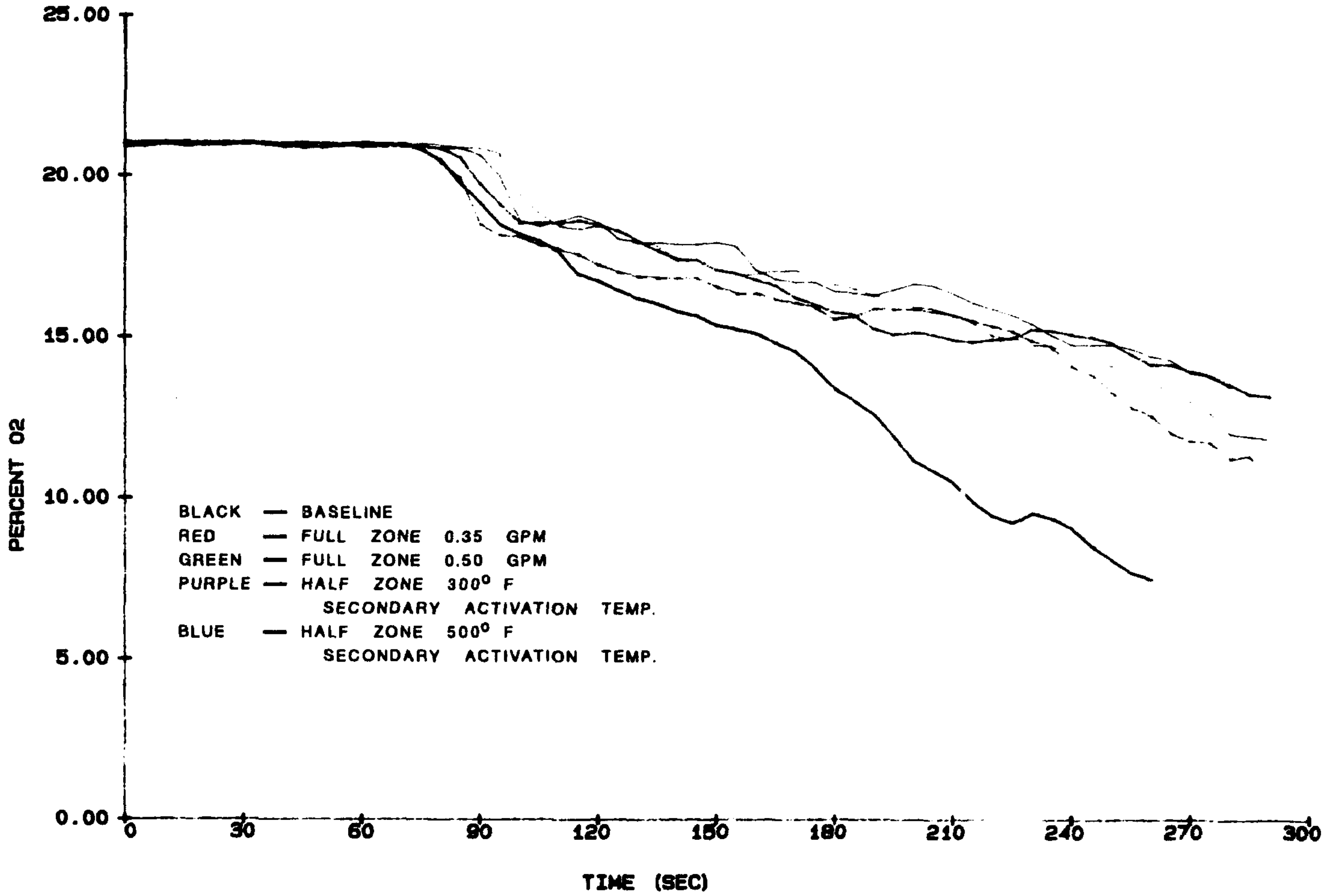


FIGURE 19. LIGHT TRANS @ STA 340, 3'6" TO 5'6"

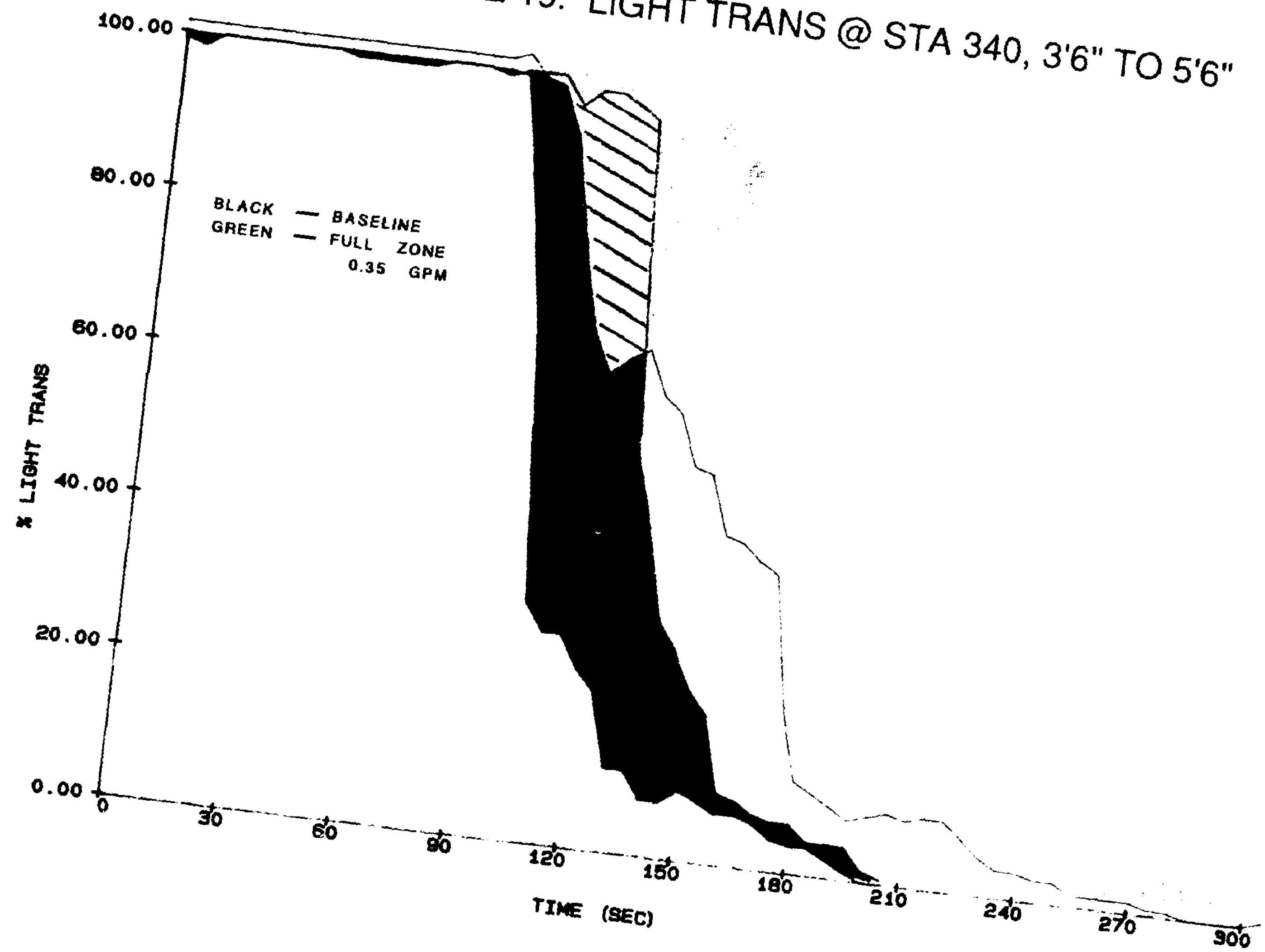


FIGURE 20. LIGHT TRANS @ STA 340, 3'6" TO 5'6"

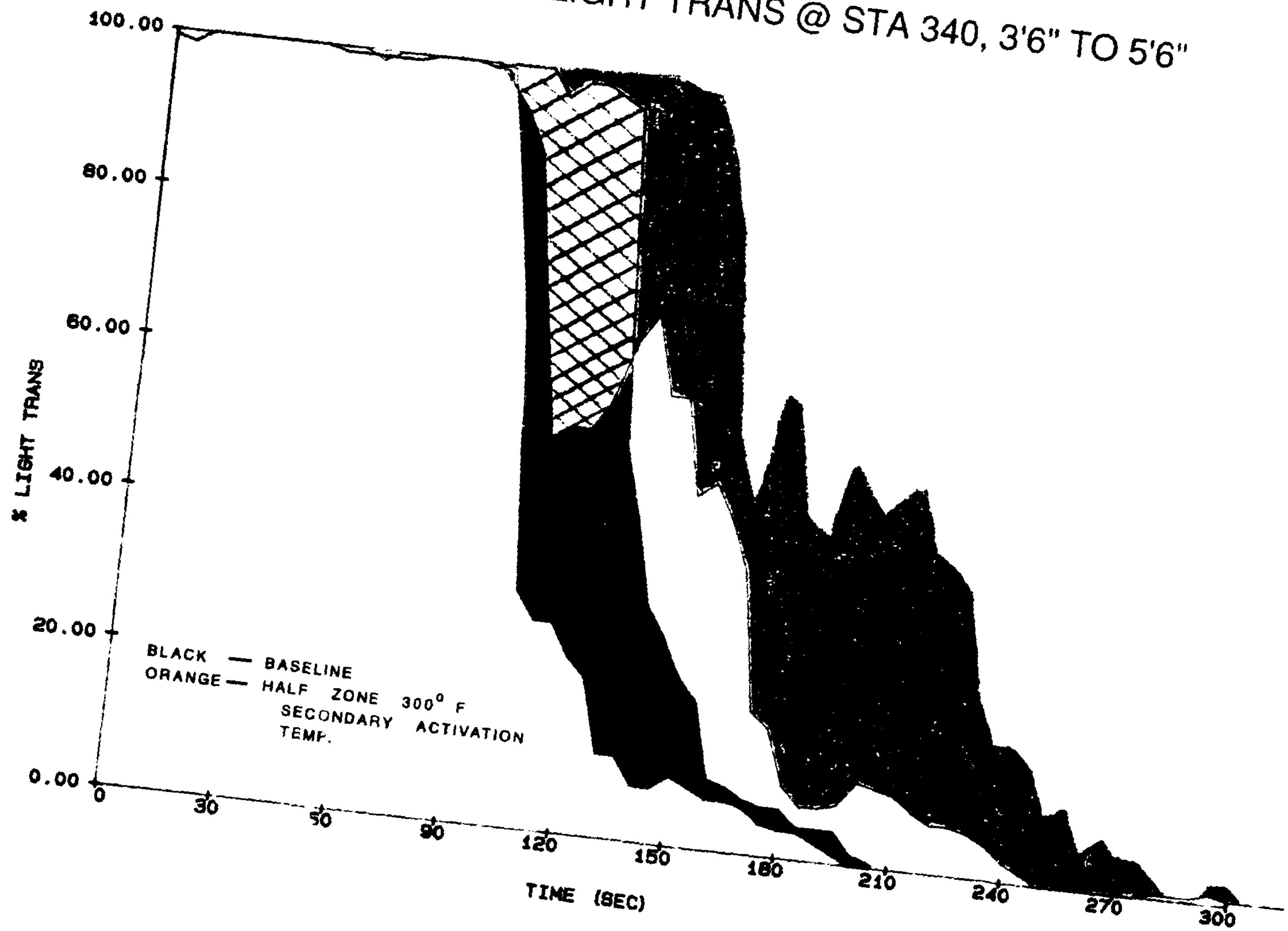


FIGURE 21. LIGHT TRANS @ STA 340, 1'6" TO 3'6"

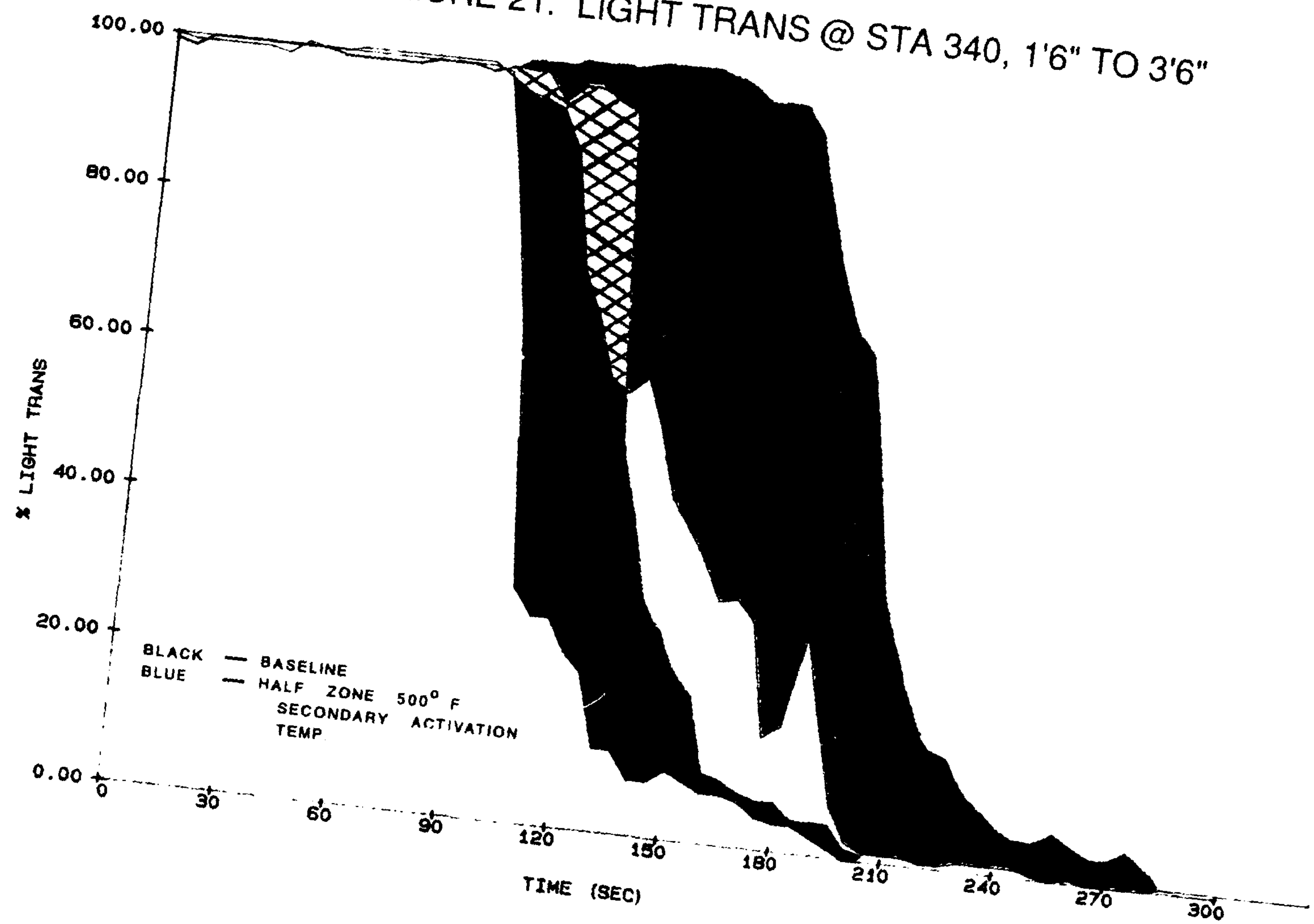


FIGURE 22. LIGHT TRANS @ STA 340, 1'6"

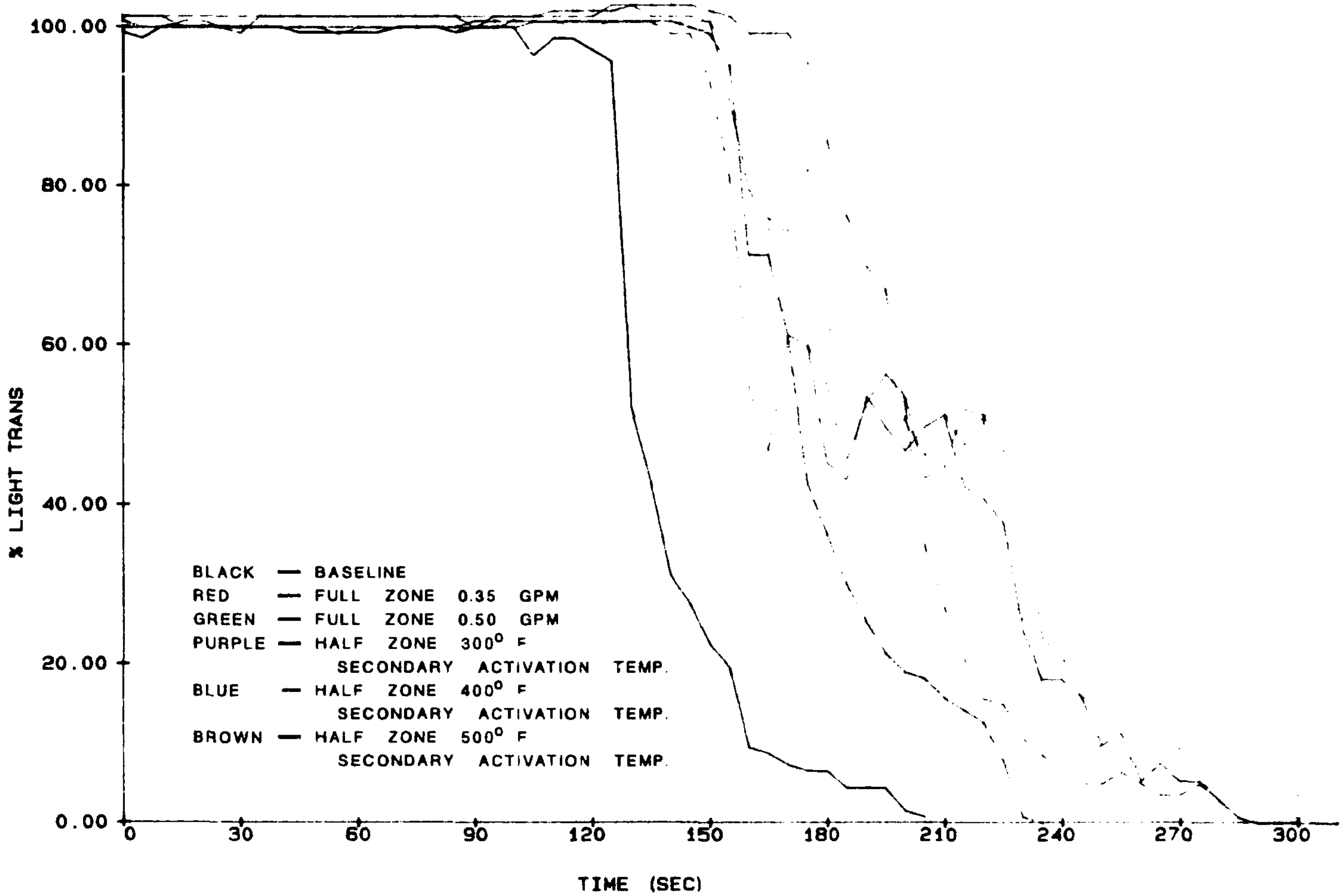


FIGURE 23. WATER CONCENTRATIONS @ STATION 80, 5'6"

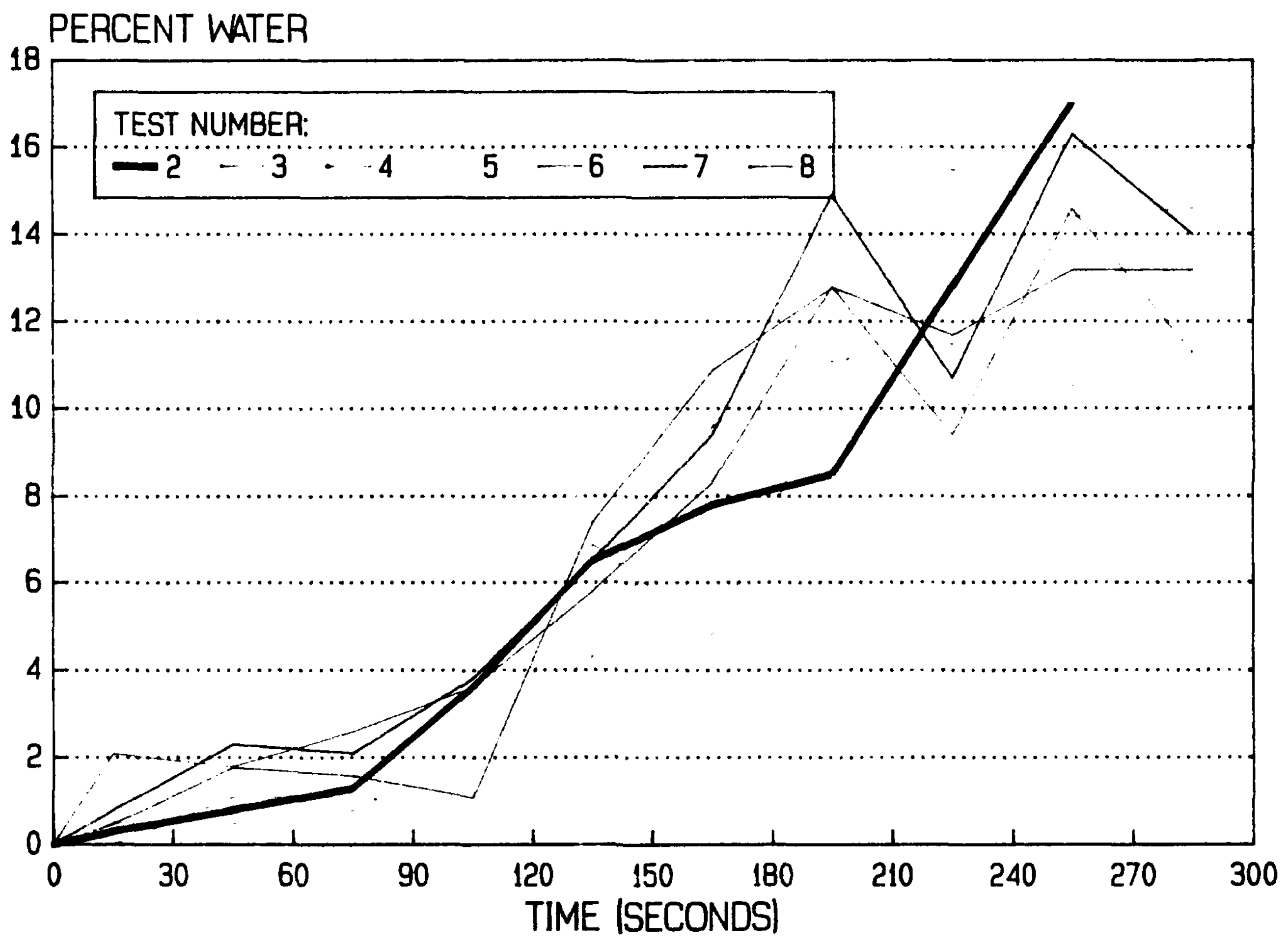


FIGURE 24. WATER CONCENTRATIONS @ STATION 580, 3'6"

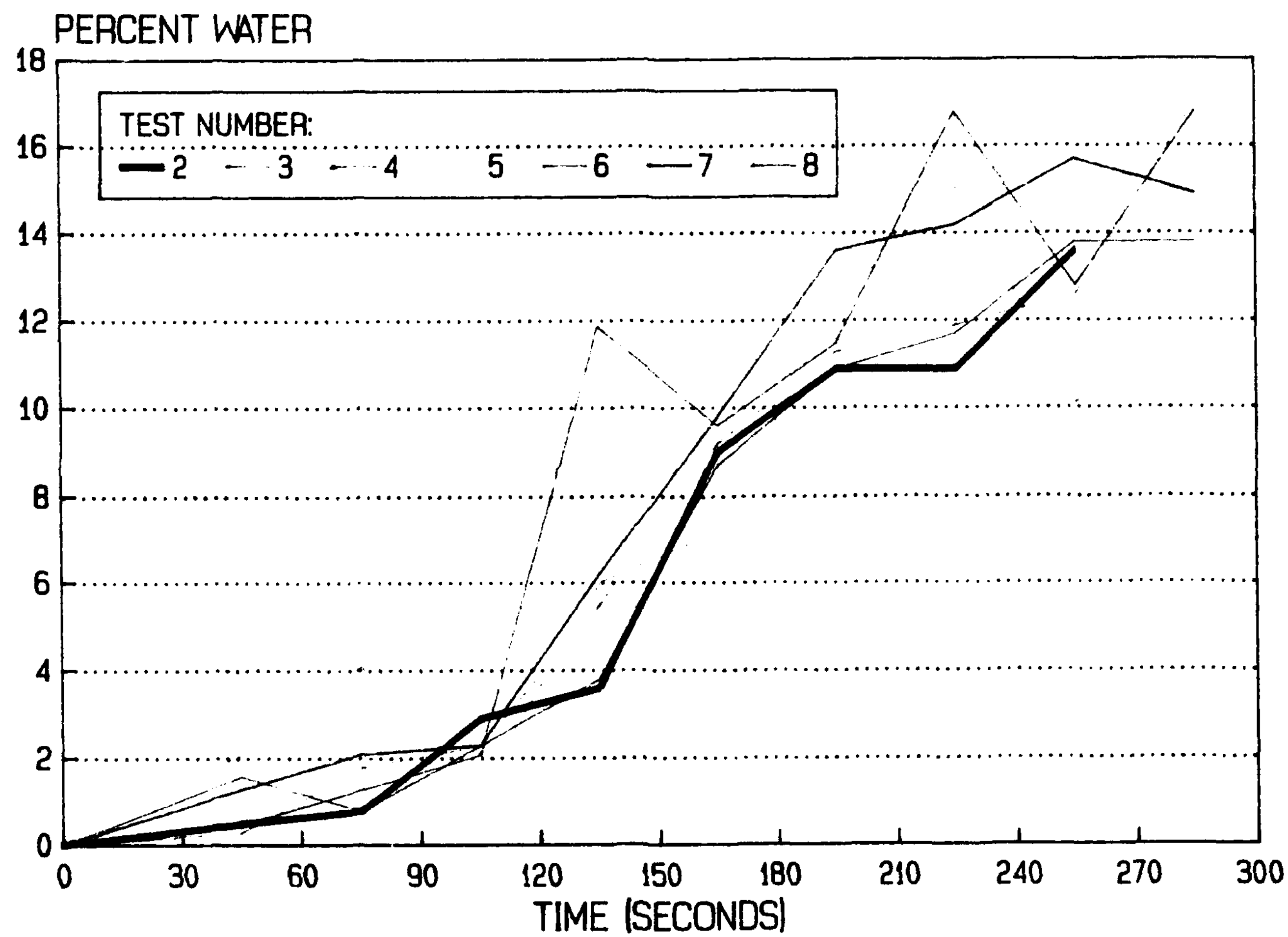


FIGURE 25. WATER VAPOR CONCENTRATIONS AS A FUNCTION OF TEMPERATURE @ STA 80, 5'6"

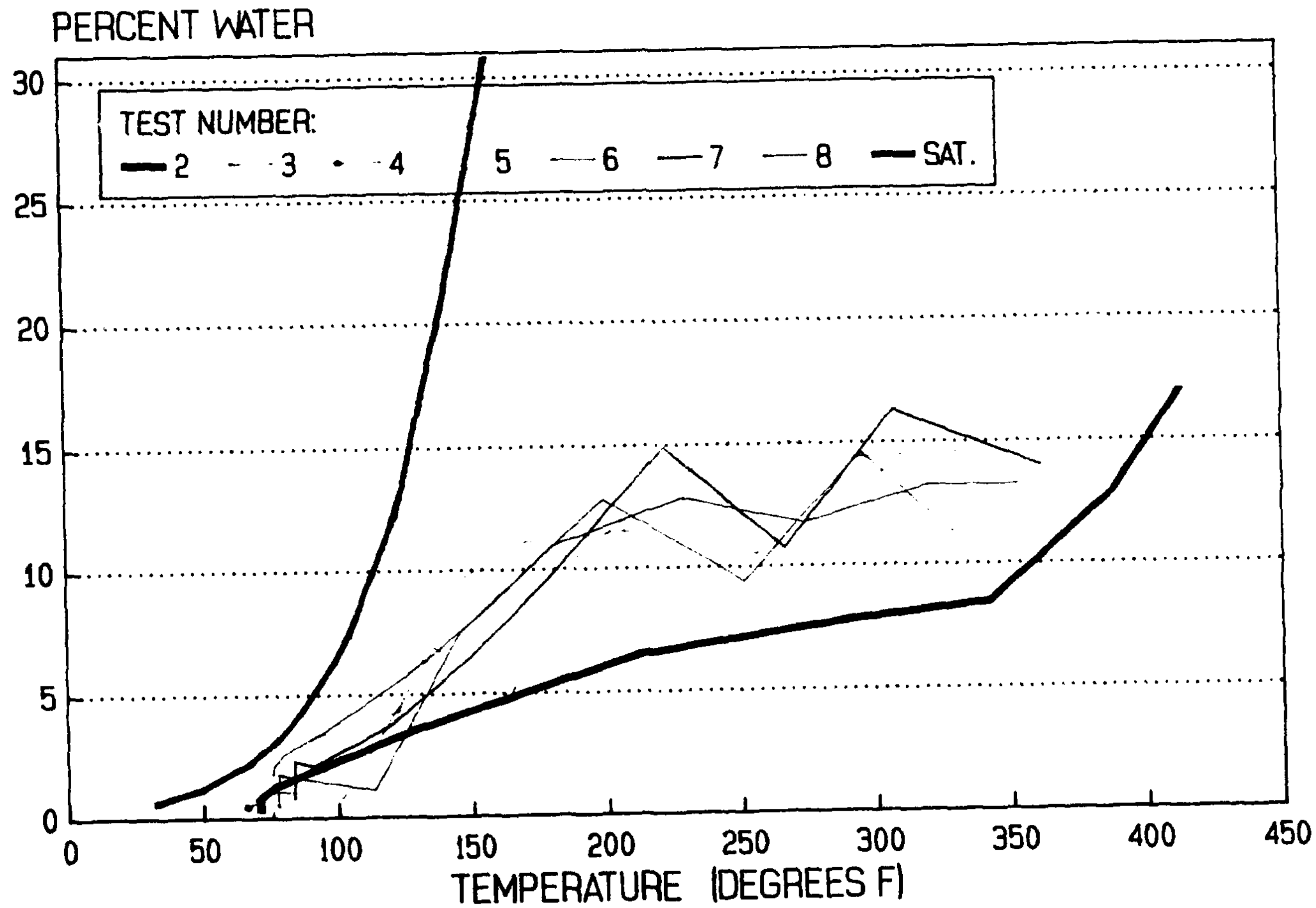


FIGURE 26. WATER VAPOR CONCENTRATIONS AS A FUNCTION OF TEMPERATURE @ STA 580, 3'6"

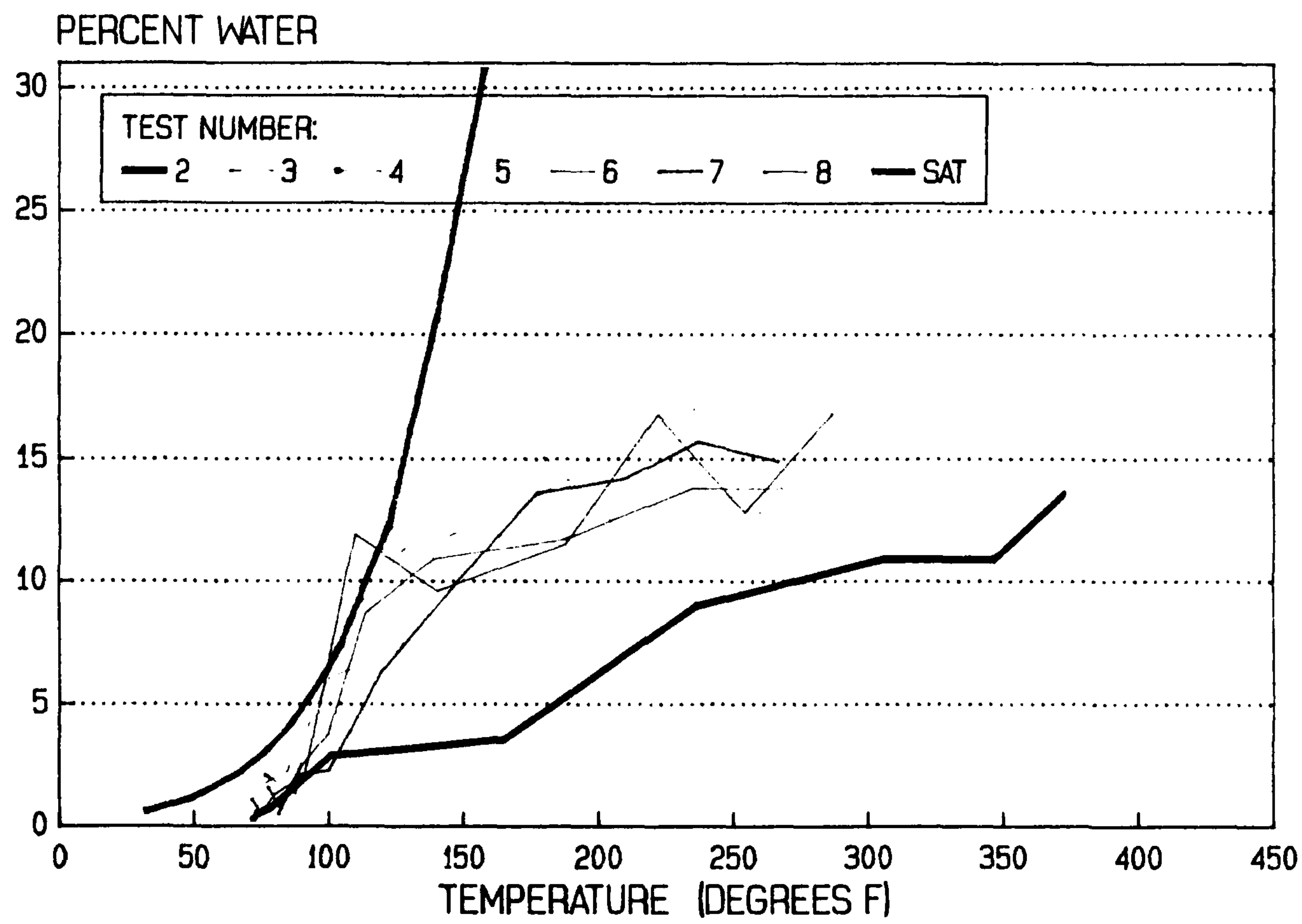


FIGURE 27. FED @ STA 580, 3'6"

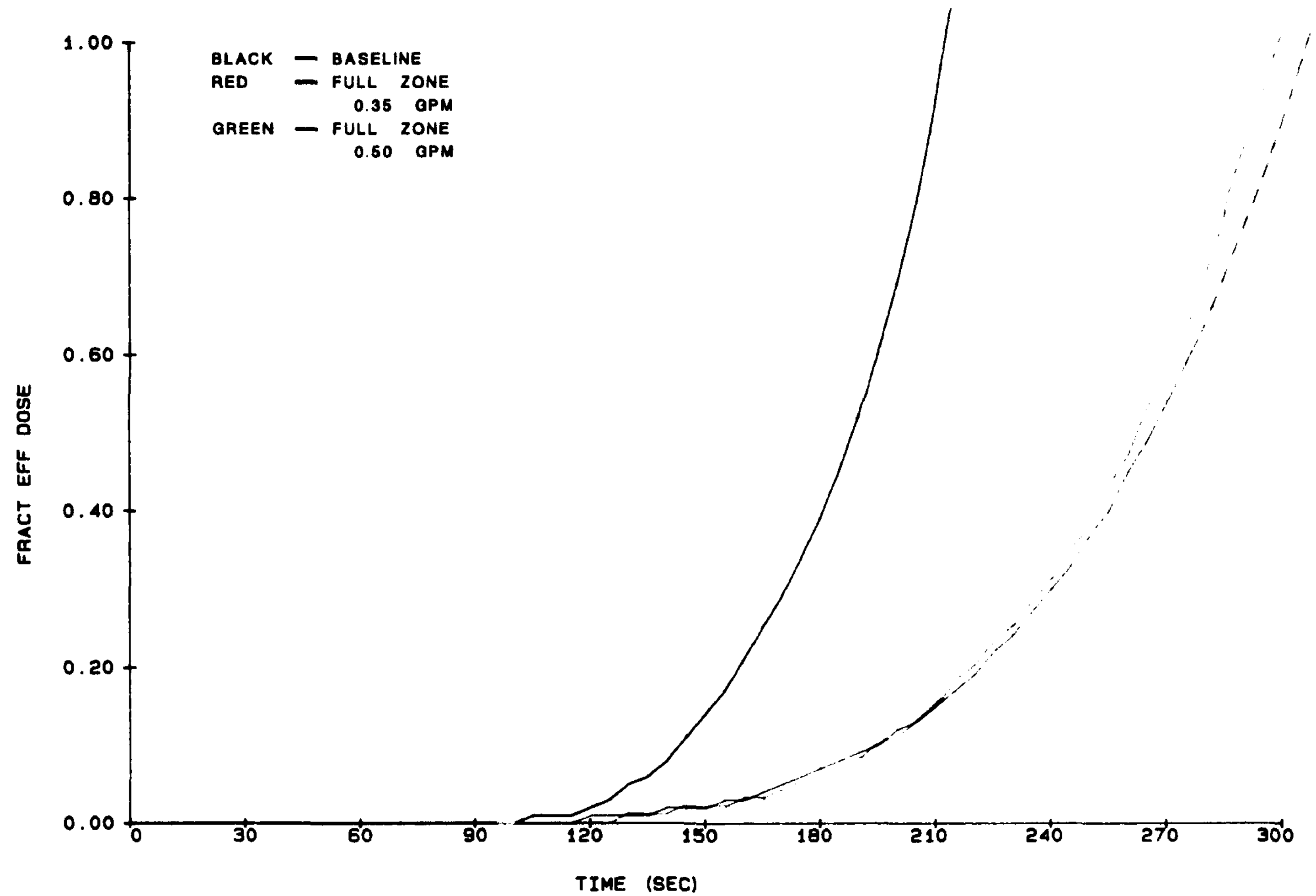


FIGURE 28. FED @ STA 80, 3'6"

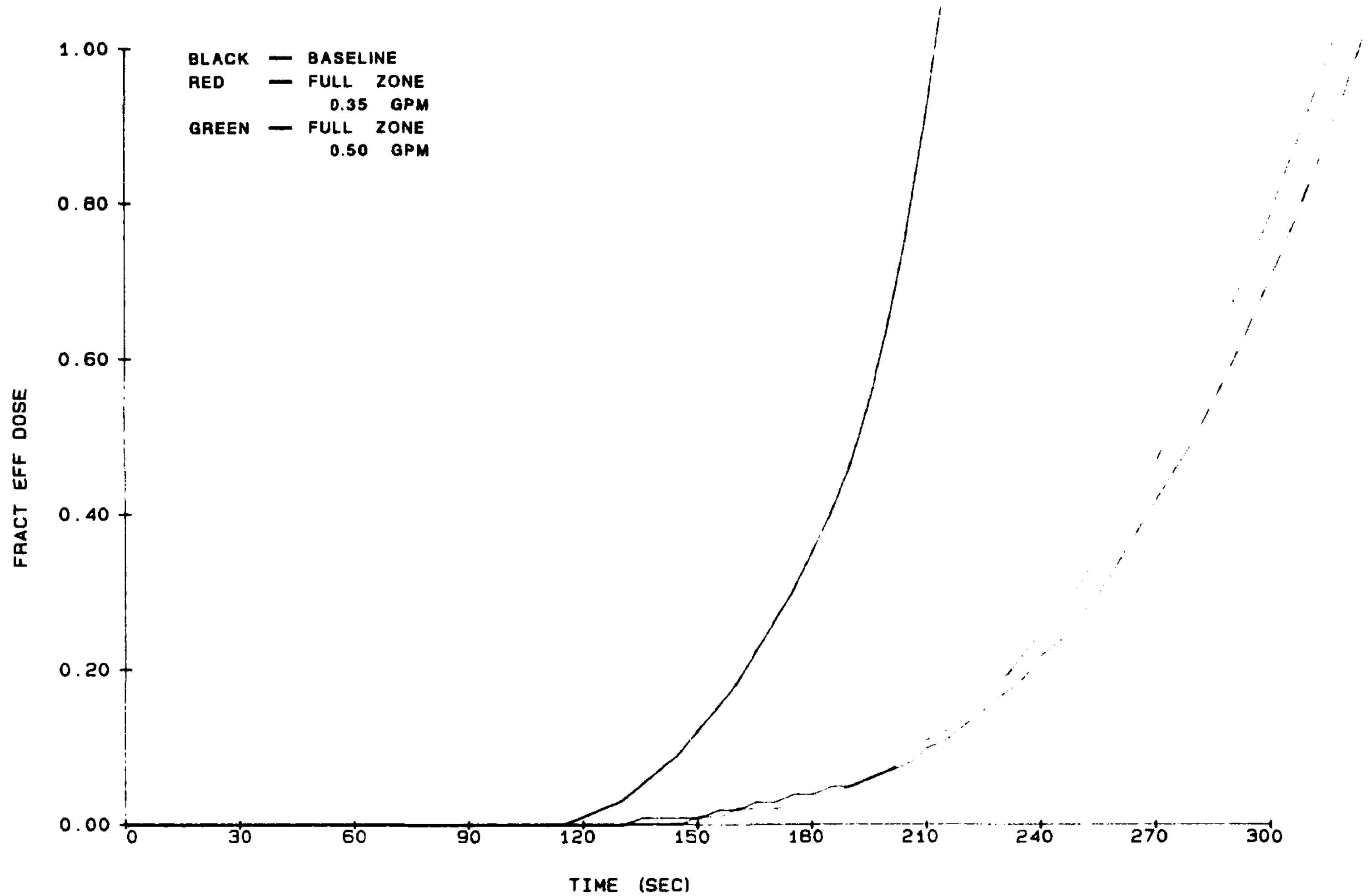


FIGURE 29. FED @ STA 80, 5'6"

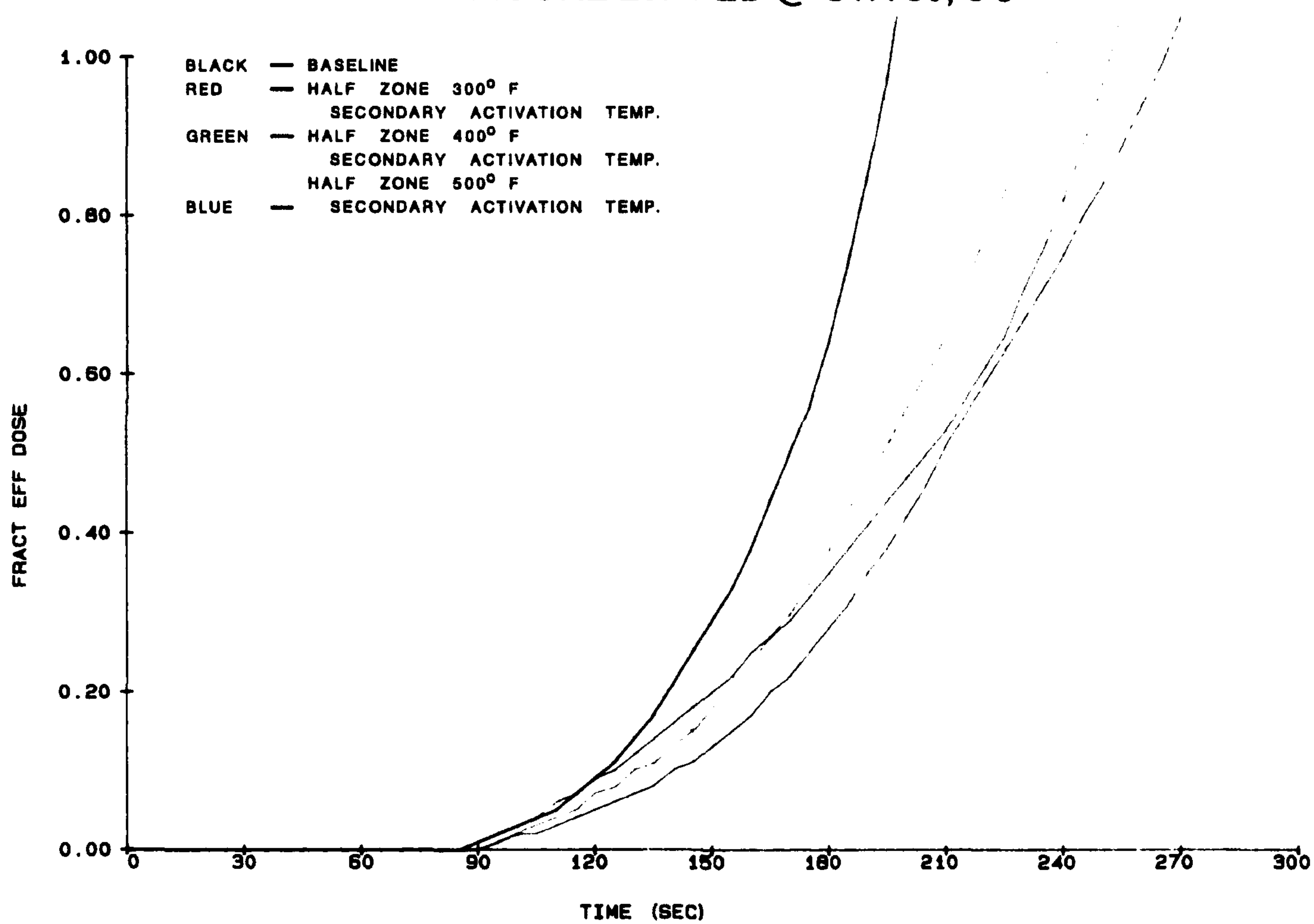
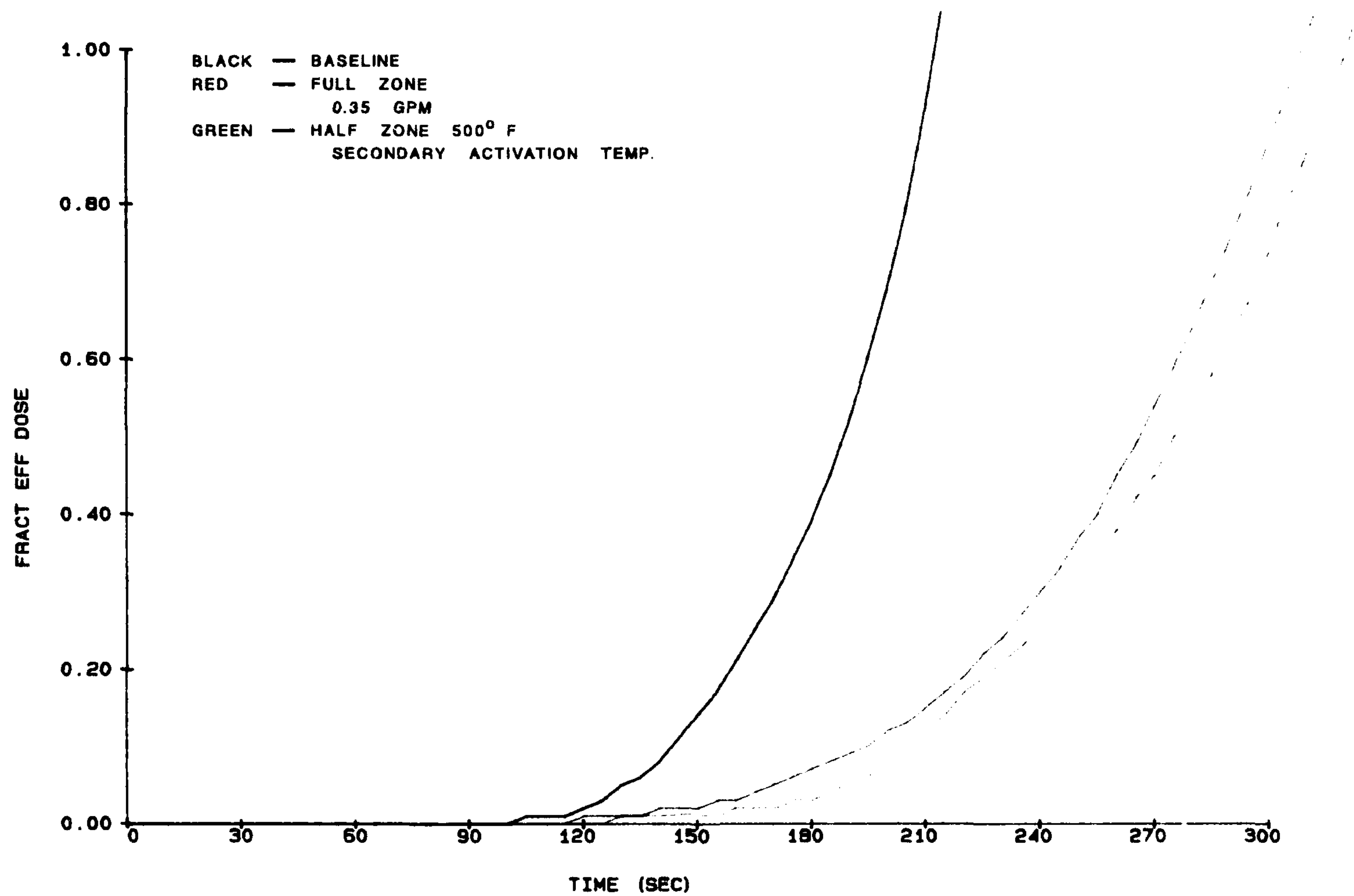
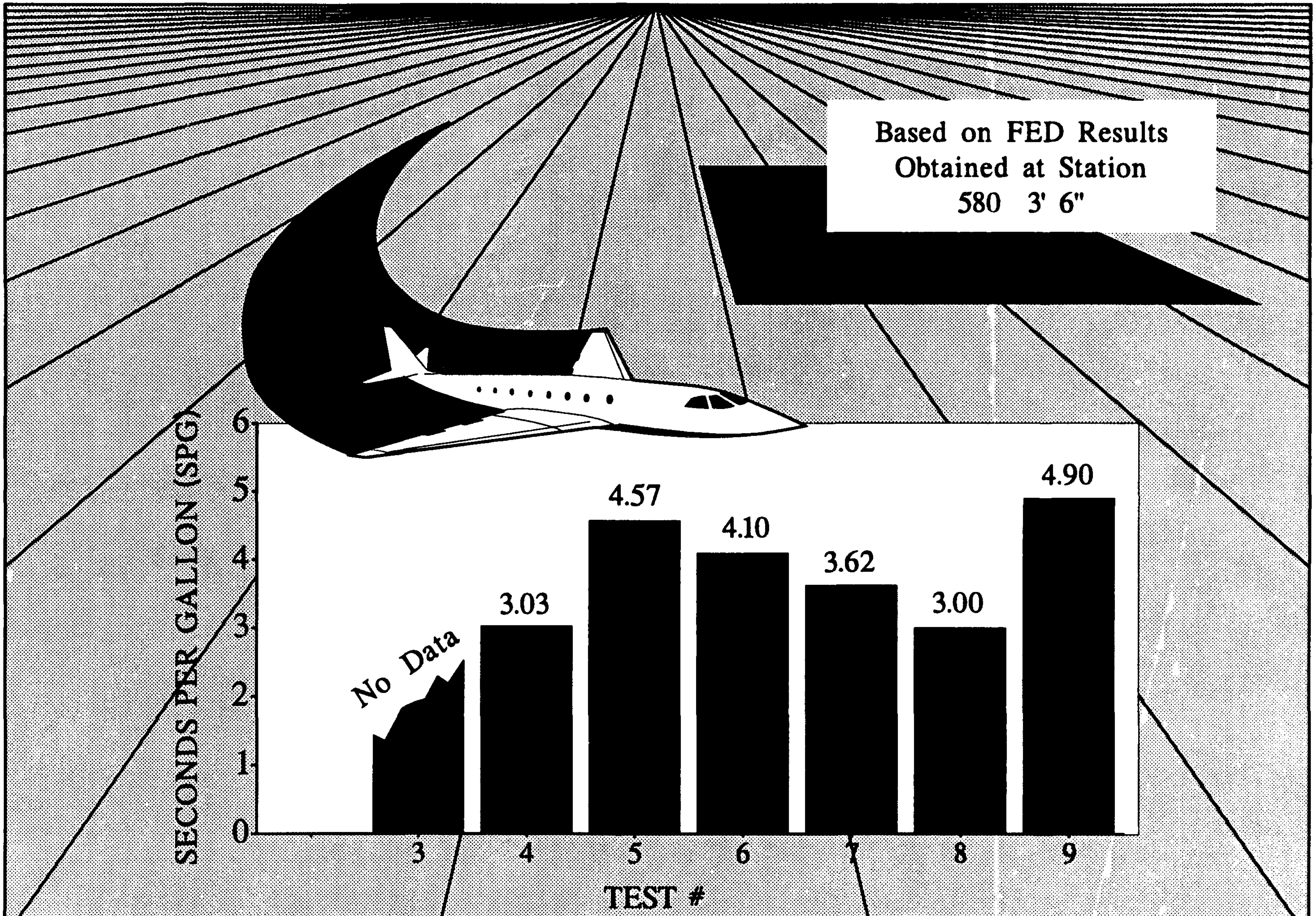


FIGURE 30. FED @ STA 580, 3'6"





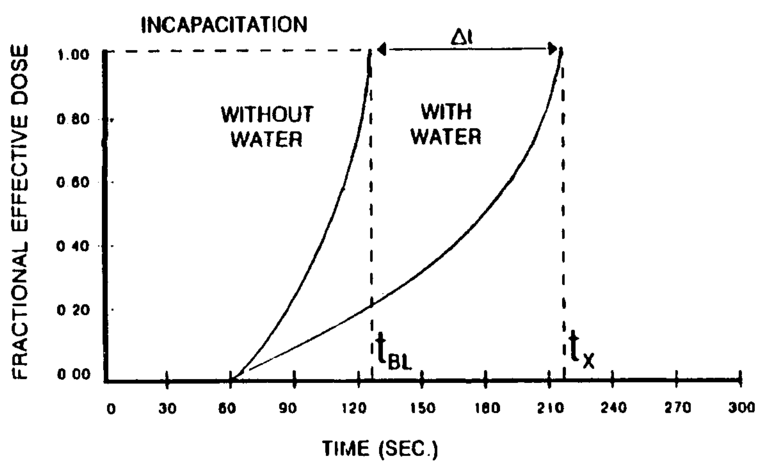
Based on FED Results
Obtained at Station
580 3' 6"
SECONDS PER GALLON (SPG)
0
1
2
3
4
5
6
No Data
3.03
4.57
4.10
3.62
3.00
4.90
3
4
5
6
7
8
9
TEST #

FIGURE 31.

SPG = "seconds per gallon"

$$= \frac{\text{additional escape time (seconds)}}{\text{quantity of water used (gallons)}}$$

$$= \frac{t}{Q_w} = \frac{t_x - t_{bl}}{Q_w}$$



Test # 3 NO DATA

Test # 4 $SPG = \frac{(304 - 213)}{30} = \frac{91}{30} = 3.03$
nozzle flowrate: 0.23 GPM

\# 5 $SPG = \frac{(309 - 213)}{21} = \frac{96}{21} = 4.57$
nozzle flowrate: 0.35 GPM

\# 6 $SPG = \frac{(299 - 213)}{21} = \frac{86}{21} = 4.10$
nozzle flowrate: 0.35 GPM

\# 7 $SPG = \frac{(289 - 213)}{21} = \frac{76}{21} = 3.62$
nozzle flowrate: 0.35 GPM

\# 8 $SPG = \frac{(276 - 213)}{21} = \frac{63}{21} = 3.00$
nozzle flowrate: 0.35 GPM

\# 9 $SPG = \frac{(316 - 213)}{21} = \frac{103}{21} = 4.90$
nozzle flowrate: 0.35 GPM

FIGURE 32. SPG CALCULATION